1971

Small computer analysis of regional ocean data.

Sanchez, Jaime Cortes

Monterey, California. Naval Postgraduate School

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JAIME SANCHEZ CORTES

United States
Naval Postgraduate School

THESIS

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by

Jaime Sanchez Cortes

Thesis Advisors: D. F. LEIPPER
K. L. DAVIDSON

September 1971

Small Computer Analysis of Regional Ocean Data

by

Jaime Sanchez Cortes
Lieutenant Commander, Colombian Navy
University of Bogota, 1967
Colombian Naval Academy, 1955

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1971

ABSTRACT

This study presents the results of an experiment in objective analysis of oceanographic data for a limited area. The objective analysis is designed to provide a reliable operational system for tactical use in coastal waters. It is shown that this approach makes it possible to obtain a very detailed analysis with good vertical consistency and that only a relatively small amount of highly accurate data is required. The procedure includes a polynomial interpolation and a dynamical interpolation. The dynamical interpolation which is introduced involves the analytical solution of a finite differential equation by means of a rotational computing molecule. The procedure requires only a small computer and little computer time. This method will provide a basis for short-time forecasts of oceanographic parameters using only small computer centers or even time sharing systems.

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AKNOWLEDGEMENT

It is time to thank the United States Navy for making it possible for the author to be at the Naval Postgraduate School, the School's faculty for giving him knowledge and means to carry out this work especially to his Co advisor Assistant Professor Kenneth L. Davidson, Department of Meteorology, whose patience, understanding and collaboration made possible the solution of so many theoretical, semantical as well as personal problems that the author had to face during the development of this work.

The author wants to thank Professor Dale F. Leipper, Chairman of the Oceanography department and Co advisor of this work, for his invaluable advice and continuous cooperation not only during the completion stage of this work but also during all the stages of its development including its planning; also, Mr. Stevens P. Tucker who kindly supplied all the data for the California coast used in this work; the W. R. Church Computer Center staff because without their continuous help and highly efficient performance this work wouldn't be possible; the Education Media Department staff who made possible a neat presentation of the drawings.

The author also wants to express his personal recognition to Admiral Jaime Parra Ramirez, Colombian Navy, to whom the Oceanography in Colombia owes its existence and whose interest in this field may have influenced the general approach and objectives of this work.

Finally, it is in order to state the author's deepest recognition to Lieutenant Colonel Fred B. Tomlinson, U. S. Army, from the Letterman

General Hospital surgery department who performed an extremely successful operation on the author's three-month old daughter during critical stages of this work making possible to finish it with clear mind and without personal worries.

I. INTRODUCTION

Analysis of oceanographic data has been traditionally a very slow and essentially a subjective process due to the time involved in an oceanographic expedition and the small amount of data obtained. Increasing the number of systematic observations in time and space requires faster analysis procedures and objective methods. Such methods will provide information for regions of sparce data. The analysis procedure should also standarize sequential analyses so that the results may be compared.

Objective analysis techniques are currently used on an operational basis by the Navy and other government agencies concerned with atmospheric phenomena. Background information available for formulating an objective analysis scheme for oceanographic data is primarily that from investigations and from experience with schemes for meteorological data. However, there are significant differences between both the type and distribution of meteorological and oceanographic data which have to be considered.

The primary purpose of most objective analysis schemes is to transform data from observations at irregularly spaced points into data at points within a regularly arranged grid (grid points). A subjective method for doing this would be to have an analyst manually (subjectively) draw isolines and then interpolate (objectively/subjectively) to obtain values at the appropriate grid points. An example of an operational grid is given in Figure 1.

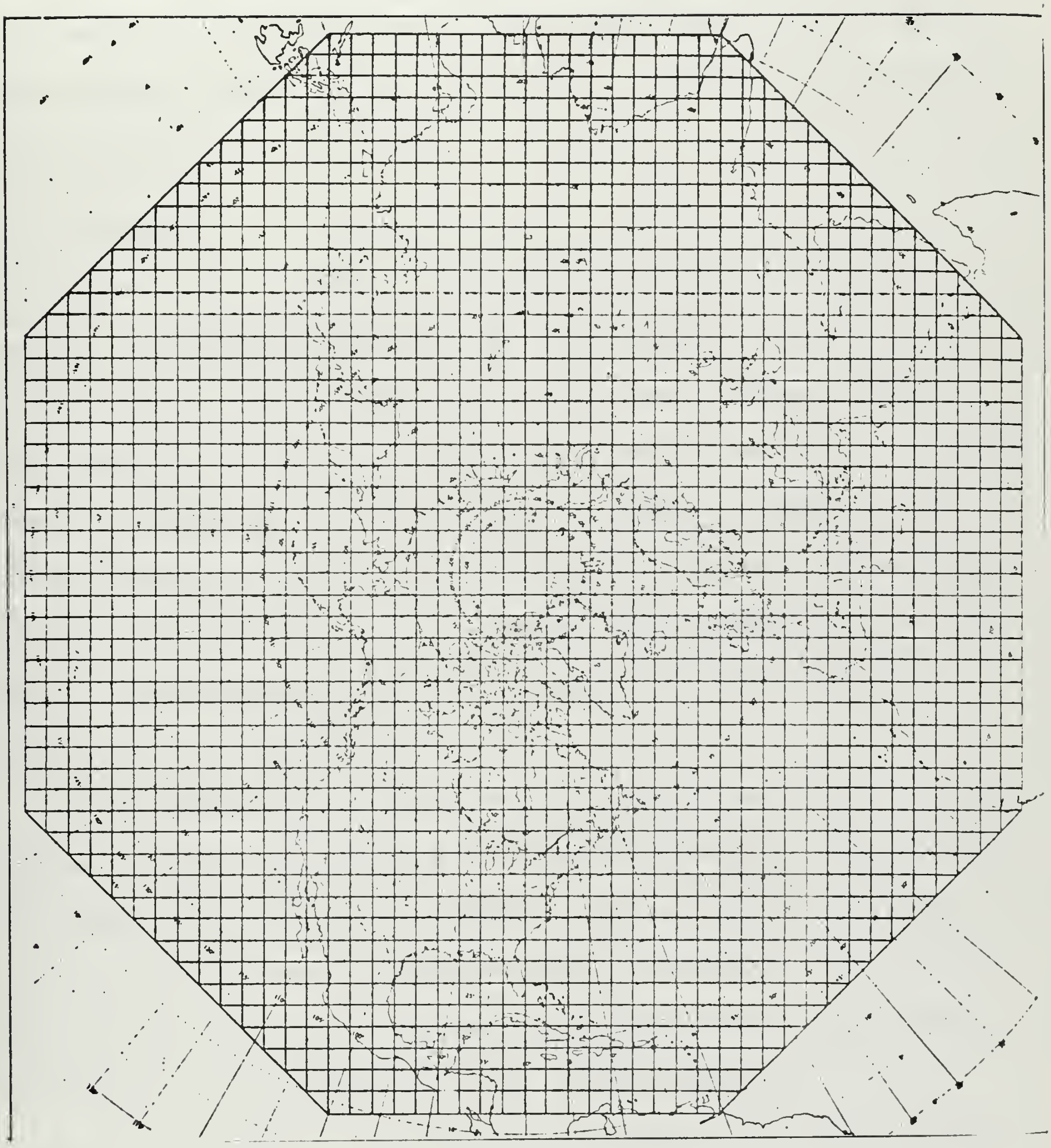

FIGURE 1. Example of the grid used by the Joint Numberical Weather Prediction Unit (After Cressman 1959)

Procedures used in objective analysis have to be systematic and quantitative so that they can be performed by numerical computations on a computer. Computer processing is by its very nature, objective. In practice, once the observations are relayed from reporting stations all procedures leading to an analyzed chart should be completed within a minimum of manual intervention.

A. BACKGROUND

Research and the subsequent development of objective analysis methods took place in response to the need to prepare large numbers of meteorological observations representing the atmosphere, both in the horizontal and vertical, for numerical weather prediction procedures. Numerical weather prediction requires, in addition to values at regularly spaced grid points, editing (removal of erroneous observations) of these data and checking for consistency and continuity in time and space. These requirements would also apply to objective analysis schemes for oceanographic data.

Once a grid of equally spaced values, checked for possible errors, is generated by an appropriate objective analysis scheme further work can be performed readily on a computer. These steps also could be performed in subjective analysis but the time required to obtain the completeness achieved by an objective analysis scheme would be out of proportion to the time needed for the computer analysis.

An early publication on the subject of objective analysis of geophysical data was by Panofsky (1949). Various approaches for performing objective analysis with meteorological data were presented during successive years by Gilchrist (1954), Bergthorsson and Doos (1955), Johnson (1957), Cressman (1959), and Smith (1962). The latter

references describe versions of operational objective analysis schemes presently used in the principal weather centers of the world. However, most of the currently used objective analysis schemes are based on the "Operational objective analysis system" described by Cressman (1959).

The general approach in these schemes is a very straightforward corrective approach in which an initial (preliminary) field is modified by available observations and the result is then used as preliminary field which is again modified with the observations but with more resolution. The repeating corrections are called scans. This process may be repeated many times but in general satisfactory results are obtained with the first or second scan.

In the corrective approach, an analytical model defines the criterian for checking the validity of observed values and determining values at grid points. Determination of grid point values from observations at nearby[1] stations is achieved by some form of interpolation. One method of interpolating for a scalar field is to represent the contours of isolines surrounding the grid point as a function of position. This may be accomplished by means of a surface least squares polynomial interpolation. The order or degree of the polynomial in the least square interpolation depends on how detailed the final field should be;

> "The degree of smoothing will depend upon the nature of the forecast and the particular model selected.....Smoothing to eliminate unwanted, though real, wave lengths has been taken to fall within the province of the forecast rather than that of the analysis." (Johnson 1957)

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[1] Nearby is normally considered to be within one grid distance.

Oceanographic analyses have been made only as a related factor in weather analysis. Climatological forecasts of ocean surface temperature anomalies have been made by Adem (1969), Jacob (1967), and Adem (1970) using the equation for the conservation of thermal energy.

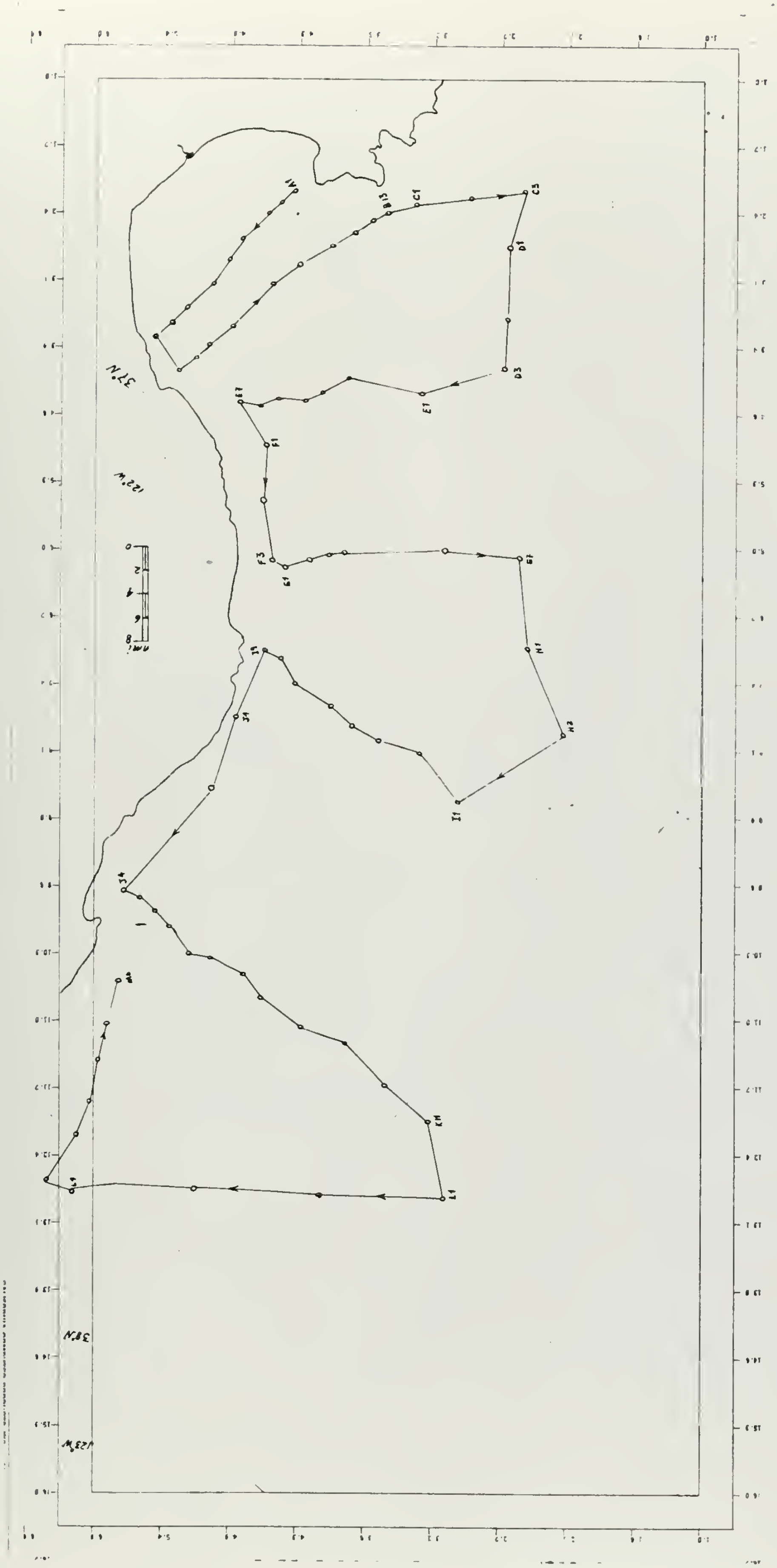
The type of data expected in an oceanographic survey introduces the problem of holes between transects and therefore the need of some type of dynamical interpolation. Typical cruise tracks appear in Figures 2 and 3. Provisions for lack of data for meteorological analysis of a given region when good data is available at the boundary have been studied by Thompson (1961), Richardson (1961), Smith (1961), and Smith (1962). The method generally used is to "advect good data from outside the region (or "hole")" (Smith 1962).

B. PURPOSE AND SCOPE OF THIS STUDY

The purpose of this study is to develop an objective analysis scheme for oceanographic data which will meet operational requirements described in the following paragraphs.

The high cost or operating oceanographic ships at sea is a primary reason to develop methods to complete instant detailed analysis. Such an analysis would show interesting features based on early observations but not considered during the initial planning which would permit scheduling of complementary observations during the same operation at sea. Furthermore, operation requirements of submarine and antisubmarine warfare have shown the need of faster and more accurate short term forecasts of oceanographic parameters which could be produced through the use of numerical procedures.

The scope is to develop a scheme which would resolve fine details. Small thermal inhomogeneities have great effect in sound propagation



37°N
122°W
38°N
123°W
nmi

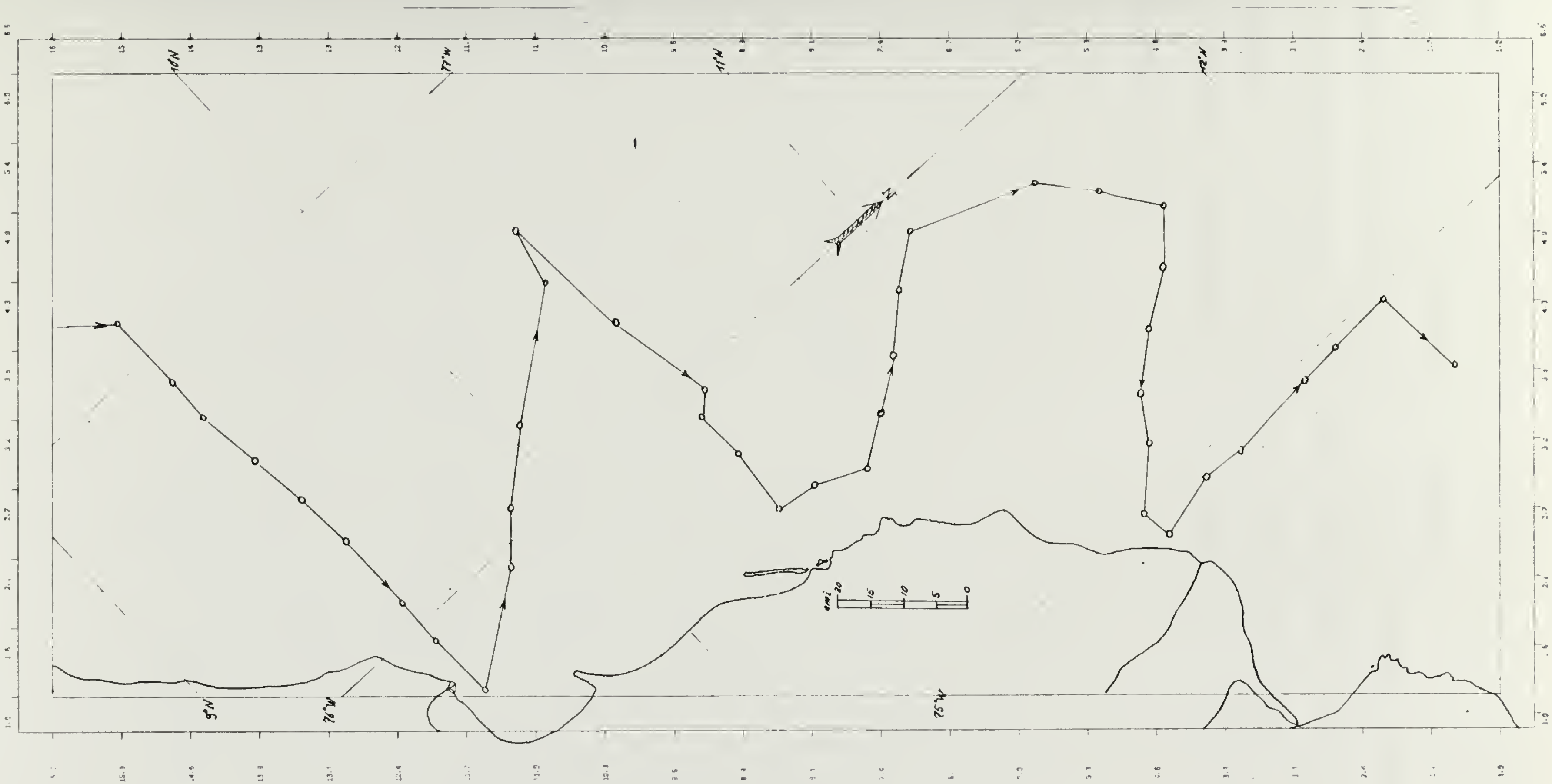


FIGURE 3. Cruise track showing station locations along Region II of Caribbean coast of Colombia (After Sanchez 1969)

especially when relatively high frequencies are used. Those fine details cannot be observed nor forecasted with large scale schemes and therefore, this study considers small scale objective analysis methods for oceanographic data. The method will include some type of dynamical interpolation. The scheme will be evaluated with respect to its use for tactical purposes and as a "feed back" for planning during oceanographic surveys.

II. APPROACH

Data obtained from the standard oceanographic stations differ from the meteorological data in the number of stations, the accuracy of observations and in the fact that the former nearly always has to be considered synoptic[1] for long time steps over small areas. In general, an initial field will not be available in oceanographic analysis nor will there be enough data to obtain a complete interpolated field. Therefore, new procedures have to be formulated in the development of the objective analysis for oceanographic data. Techniques described above for meteorological analysis will be applicable only in a relatively small part in this particular problem.

The objective analysis developed is a numerical scheme in which a least squares surface polynomial is used for interpolating and smoothing the available data to nearby grid points. Then a dynamical interpolation is used to compute values at those grid points which are in "holes" or regions of no data. The dynamical interpolation is achieved by means of a rotational molecule.

A. POLYNOMIAL INTERPOLATION

The first step in the scheme is to reduce the original data to neighboring[2] grid points using surface least squares polynomial

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[1] Synoptic data represent observations taken simultaneously.

[2] Neighboring refers to data within one grid distance.

interpolations. A second degree polynomial is used when six or more data points are available in a given square around the grid point, and first degree polynomial when only four or five points are available. A weighted gradient propagation is used when only two or three data points are available. When only one observation is available in the entire square around the grid point some criteria about the distance is established and if this distance is, say, less than five miles the best approximation will be to give the same value to the grid point, otherwise this value is neglected.

The polynomial solved for the second degree polynomial interpolation is:

$$a_{00} + a_{10}X + a_{11}XY + a_{20}X^2 + a_{01}Y + a_{02}Y^2 \qquad (1)$$

The first degree interpolation formula is:

$$a_{00} + a_{10}X + a_{11}XY + a_{01}Y \qquad (2)$$

and the weighted gradient propagation formula is:

$$Z_G = Z_1 + W \left\{ \frac{(Z_1 - Z_2)[X_1(Y_1 - Y_2) + Y_1(X_1 - X_2)]}{(X_1 - X_2)(Y_1 - Y_2)} \right\} \qquad (3)$$

Where $W = 1.0$ inside the square of the grid point considered.

The matrix obtained in the first two cases is solved for a_{00}, since the grid point is at location $0,0$, using the subroutine SIMQ from the computer library of the Naval Postgraduate School.

This scheme for obtaining values for some grid points enables the maximum use of data.

In meteorological analysis the regression has been used and also the correction method. In the latter, it is assumed that the difference between the preliminary value and the observed value at a given station is equal to the difference between the derived value and the preliminary value at the grid point. Another approach in the correction method is to assume that the gradient of the preliminary field at the grid point is representative for all the area between grid points and the station (gradient propagation). Then the correction is a function of the distance between grid points and station. In these procedures a statistically determined weight function (weighted gradient propagation) is required.

In all interpolation methods, the distance between observations and a grid point becomes a crucial factor; for example,

> "Quite often it is not possible to get a reasonable analysis only by means of interpolation between synoptic observations. It is quite clear that the distance between observations must be small compared with the size of the system to be analyzed." (Bergthorsson and Doos 1955)

Therefore, distance limitations introduce the need for a dynamical interpolation whenever "holes" are present.

B. DYNAMICAL INTERPOLATION

The initial step in developing a suitable dynamic interpolation is simplification of the basic conservation equations for a scalar quantity in a fluid medium. In order to apply a simplified equations to a set of

regular horizontally and vertically distributed data, certain assumptions are required about the flow characteristics. These assumptions have to be based on conditions observed or generally accepted for an oceanographic environment. The simplification of these equations, the assumptions involved, and the numerical procedures used to apply the final form of the equation are discussed in the following paragraphs.

1. Analytical Model

Consider the analysis of a conservative scalar field. The available data will represent quasi-synoptic observations provided by standard stations in a relatively small area of the ocean. Therefore, some of the following information could be available for each station:

(1) Temperature

(2) Salinity

(3) Wind velocity

(4) Dynamic height anomaly

(5) Sigma-t

(6) Sound velocity

at observation depths and at standard depths.

An analytical model for analysis of temperature, salinity and sound velocity would be based on the following steady state conservation equation for a non divergent fluid:

$$u\frac{\partial()}{\partial x}+v\frac{\partial()}{\partial y}+w\frac{\partial()}{\partial z}=\frac{\partial}{\partial x}\left[K_x\frac{\partial()}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_y\frac{\partial()}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_z\frac{\partial()}{\partial z}\right] \quad (4)$$

where

u, v, and w are the components of the velocity vector

K is the eddy viscosity coefficient

Studies have shown that the following approximation is possible:

$$\frac{\partial}{\partial z}\left[K_z \frac{\partial()}{\partial z}\right] \simeq W \frac{\partial()}{\partial z} \qquad (5)$$

where;

"The condition for neglecting the horizontal terms is that they approximately cancel each other. Since those terms have been shown to be of the same order of magnitude and opposite signs, this condition is possible." (Overstreet and Rattray 1969)

Assuming condition (5) the conservation equation becomes:

$$U \frac{\partial()}{\partial x} + V \frac{\partial()}{\partial y} = \frac{\partial}{\partial x}\left[K_x \frac{\partial()}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y \frac{\partial()}{\partial y}\right] \qquad (6)$$

Assuming isotropy and horizontal homogeneity the two dimensional Equation (6) becomes:

$$U \frac{\partial()}{\partial x} + V \frac{\partial()}{\partial y} = K_H\left[\frac{\partial^2()}{\partial x^2} + \frac{\partial^2()}{\partial y^2}\right] \qquad (7)$$

or

$$\frac{U}{K_H}\left[\frac{\partial()}{\partial x} + P \frac{\partial()}{\partial y}\right] = \frac{\partial^2()}{\partial x^2} + \frac{\partial^2()}{\partial y^2} \qquad (8)$$

for $U \neq 0$

where $P = \frac{v}{u}$

P can be computed for each grid point if the direction of the current at each grid point is known. However, unless direct measurements of the current have been made near each grid point this is not generally the case. Therefore, the next best solution is to compute the current for each station using available data and extrapolate or interpolate it to the nearest grid points assuming that the current is uniform in the area.

The current consists of four components

$$\vec{V} = \vec{V_d} + \vec{V_g} + \vec{V_b} + \vec{V_T} \qquad (10)$$

where

$\vec{V_d}$ is the drift current due to wind action

$\vec{V_g}$ is the geostrophic current computed from the density field

$\vec{V_b}$ is the barotropic current

$\vec{V_T}$ is the tide current

If a strong barotropic current, $\vec{V_b}$, is present in the region to be analyzed, climatological data would have to be considered for its definition.

Tidal currents may be significant because oceanographic data is only quasi-synoptic as noted before. However, currents considered are generally time averaged for the entire time of all the observations. Therefore, observations would represent a time lapse of two or three days or at least 24 hours. It is possible, therefore, to neglect tidal

currents in the average. However, when the observations are truly synoptic, tidal currents must be considered. i. e.

"Tidal currents are simply the water movements generated by tidal forces. Since tidal forces which produce tidal currents are periodical and these currents are generally only important in shallow water, tidal currents will not be considered as part of the advection problem." (Ocean Thermal Structure Forecasting, ASWEPS manual series, v. 5, p. 21)

Hereafter we neglect tidal and barotropic currents so the horizontal components of the current vector become:

$$u = u_d + u_g \qquad (11)$$

$$v = v_d + v_g$$

and

$$P = \frac{v_d + v_g}{u_d + u_g}$$

Similar formulae have been suggested by Arthur (1966) and Adem (1970).

These velocity components can be computed from the data available in a standard oceanographic station.

Considering the drift current, we examine possible relation between it and the obsereved wind. Denoting the surface wind velocity as Va, the following formula apply for Va along the Y-axis:

$$u_d = V_o e^{-(\pi/D)z} \cos\left(45^\circ - \frac{\pi}{D} z\right) \qquad (12)$$

$$v_d = V_o e^{-(\pi/D)z} \sin\left(45^\circ - \frac{\pi}{D} z\right)$$

where

$$V_0 = \frac{0.0259\sqrt{|V_a|}}{\sqrt{\sin\varphi}}$$

$$D = \frac{3.67\sqrt{|V_a|^3}}{\sqrt{\sin\varphi}} \qquad \text{for } |V_a| \leq 6 \text{ m/sec.}$$

and

$$V_0 = \frac{0.0126\,|V_a|}{\sqrt{\sin\varphi}}$$

$$D = \frac{7.6\,|V_a|}{\sqrt{\sin\varphi}} \qquad \text{for } |V_a| > 6 \text{ m/sec.}$$

φ is the latitude

For the general case, when the Y-axis is not along the wind direction Equations (12) becomes (Adem 1970),

$$\bar{U}_d = \frac{0.0126}{\sqrt{\sin\varphi}}\left(U_a \cos\theta - V_a \sin\theta\right)$$

$$V_d = \frac{0.0126}{\sqrt{\sin\varphi}}\left(V_a \cos\theta - U_a \sin\theta\right) \tag{13}$$

Where θ is the angle between the surface current and the surface wind. θ is positive when the current is to the right of the surface wind.

The geostrophic current (U_g, V_g), between two stations may be computed from the dynamic height anomaly using the Ekman approximation:

$$\frac{1}{f} U_{p,\alpha} = g i_{p,y} = 10 \frac{\partial D}{\partial y} = 10 \frac{\partial \Delta D}{\partial y}$$

$$\frac{1}{f} V_{p,\alpha} = - g i_{p,x} = - 10 \frac{\partial D}{\partial x} = - 10 \frac{\partial \Delta D}{\partial x} \tag{14}$$

where f is the Coriolis parameter

ΔD is the geopotential anomaly

Assuming that the density increases steadily with depth, the relative geostrophic current between two stations A and B, can be expressed as

$$V_A - V_B = \frac{10 f}{L} \left(\Delta D_A - \Delta D_B \right) \tag{15}$$

where L is the distance between A and B

A further simplification of Equation (11) may be achieved assuming that the geostrophic current has no contribution to the advection of density anamolies;

> "The major contribution to advection (of heat) comes from the wind drift current since the slop current is assumed to be geostrophic, or flowing rarallel to the isotherms. That is, there is no advection (of heat) by water flowing parallel to the isotherms; only cross section flow causes a change in the temperture at a point." (Ocean Thermal Structure Forecast, SP-105, ASWEPS manual series, v. 5, p. 33)

If this approximation can be accepted, Equation (11) becomes,

$$V = V_d$$

$$U = U_d \tag{16}$$

$$P = \frac{v_d}{u_d}$$

Therefore, many degrees of approximation may be used to compute P and they can be summarized in three cases:

a. Currents at the station are known. If the true current has been measured at each station, P may be computed directly or if the current has been computed, P may be computed from Equation (11). The same P may be used to nearby grid points provided the changes in current direction are not too large relative to the grid scale.

b. The wind velocity is known but the true current is not known for each station. In this case only the drift current can be considered and Equation (16) must be used to obtain the direction of the current for the grid points using the wind direction nearby. Also, in this case empirical consideration may be used for allowing for the drift current. These empirical considerations are: When slope and gradient currents (due to mass transport by the wind) have been set up, they affect the direction of the original wind driven current, and when a steady state has been reached, the deflection of the surface from the down wind direction will be reduced to near 20 degrees at low wind speeds or to less than 12 degrees at high wind speeds (Summary of Technical Reports of the National Research Committee, v. 6A), (Ocean Thermal Structure Forecasting, SP-105, ASWEPS manual series, v. 5), (Hubert 1964).

c. Only the wind field is known but other factor may be important. This situation may arise when the coast or bottom topography would invalidate the assumption that the current is at a constant angle

to the wind direction. For this case it is possible to use the following relation to obtain as estimate of the direction of the current at each grid point.

$$K \propto \vec{V} \qquad \text{(Kitaigorodskii 1961)}$$

and therefore,

$$\frac{|\vec{V}|}{K} = \text{COSTANT} = \text{RATIO}$$

where $\vec{V}$ is the fluctuating velocity vector.

However, sufficient surrounding data are required to apply a numerical solution for obtaining these variables. In order to compute $\frac{|\vec{V}|}{K}$ a P value, from the wind field is assumed for each grid point as in b. or for the whole grid if the wind field is more or less uniform. Using the assumed P, values of U/K are computed for all possible grid points using Equation (8). The numerical sheme to perform this will be explained in the next section.

Defining $$\frac{\vec{V}}{K} = \frac{u}{K}\hat{i} + \frac{v}{K}\hat{j}$$

and assuming that eddies present in the area may introduce a great range of directions in the fluctuating velocity and given that $\frac{|V|}{K}$ is a constant, the maximum value of U/K should correspond to a minimum value of v/K . Also, if v/K is small enough, it is possible the approximation

$$\frac{|V|}{K} \simeq \frac{u}{K}\text{maximum} \simeq \text{RATIO}$$

This approximation can be made if it is assumed that the mean current is thermohaline and therefore flows parallel to isotherms so it does not contribution in the advection of heat.i. e.

$$\cancel{\bar{\vec{V}}\cdot\nabla T}^{\,0} + V\cdot\nabla T = \nabla^2 T$$

$$\text{IF} \quad \bar{\vec{V}} \perp \nabla T$$

Therefore, only the fluctuating component is obtained when $\nabla^2 T$ and ∇T are computed from a field of temperature to solve for V . For each grid point at which U/K is computed a $\mathcal{V}$/K can be obtained using the formula

$$\frac{\mathcal{V}}{K} = \left[\left(\frac{|V|}{K}\right)^2 - \left(\frac{U}{K}\right)^2\right]^{1/2} \doteq \left[\left(\frac{U}{K}\,max.\right)^2 - \left(\frac{U}{K}\right)^2\right]^{1/2} \qquad (17)$$

and the new P = $\dfrac{\mathcal{V}/K}{U/K} = \dfrac{\mathcal{V}}{U}$

Using this U/K and the new P Equation (8) can be solved for T at next grid point if enough nearby grid values exist to use the rotational computing molecule presented in the numerical model (seccion 2).

The procedure above can be repeated many times but it has been observed that usually the first approximation is satisfactory. Because the quadratic equation (17) has two solutions, the wind field is used in the selection of the correct solution. This choice can be objective and included in the computer program.

2. The Numerical Model

Knowing P, U/K can be computed whenever the parameter is known in four neighboring grid points and then, using this value of U/K and the corresponding P the next unknown grid point parameter can be computed. The problem reduces to solving the differential equations

$$\frac{U}{K_H}\left[\frac{\partial()}{\partial x} + P\frac{\partial()}{\partial y}\right] = \frac{\partial^2()}{\partial x^2} + \frac{\partial^2()}{\partial y^2} \tag{8}$$

$$\frac{W}{K}\frac{\partial()}{\partial z} = \frac{\partial^2()}{\partial z^2} \tag{5A}$$

The corresponding Finite Differential Equations may be solved using the same scheme.

The following is a description of a direct solution of the partial differential equations by means of a rotating computational molecule in such a way that a solution is possible even though data are scarce.

The horizontal continuity equation, Equation (8), may be approximated by the following computational molecules:

(1) a.

$$Z_P(K,L) = 4.0 * Z(K+1,L+1) - Z(K,L+2) - Z(K+2,L) - Z(K+2,L+2)$$
$$- \frac{(U^2+V^2)^{1/2}}{K * XR}\left[Z(K+1,L+1) - Z(K+2,L+2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{(U^2+V^2)^{1/2}}{2.0*K*XR}\left[Z(K,L+2) - Z(K+2,L)\right]$$

(2) a. $$Z_p(K,L) = -\left(\frac{XSC}{YSC}\right)^2\left[Z(K+1,L+1) - 2.0*Z(K,L+1) + Z(K-1,L+1)\right]$$

$$+2.0*Z(K,L+1) - Z(K,L+2) - \frac{P*U}{K*YSC}\left[Z(K,L+1) - Z(K,L+2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{U}{2.0*K*XSC}\left[Z(K-1,L+1) - Z(K+1,L+1)\right]$$

(3) a. $$Z_p(K,L) = 4.0*Z(K-1,L+1) - Z(K,L+2) - Z(K-2,L) - Z(K-2,L+2)$$

$$-\frac{(U^2+V^2)^{1/2}}{K*XR}\left[Z(K-1,L+1) - Z(K-2,L+2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{(U^2+V^2)^{1/2}}{2.0*K*XR}\left[Z(K,L+2) - Z(K-2,L)\right]$$

(4) a. $$Z_p = -\left(\frac{XSC}{YSC}\right)^2\left[Z(K-1,L+1) - 2.0*Z(K-1,L) + Z(K-1,L-1)\right]$$

$$+2.0*Z(K-1,L) - Z(K-2,L) - \frac{U}{K*XSC}\left[Z(K-1,L) - Z(K-2,L)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{V}{2.0*K*YSC}\left[Z(K-1,L+1) - Z(K-2,L-2)\right]$$

(5) a. $$Z_p(K,L) = 4.0*Z(K-1,L-1) - Z(K-2,L) - Z(K,L-2) - Z(K-2,L-2)$$

$$-\frac{(U^2+V^2)^{1/2}}{K*XR}\left[Z(K-1,L-1) - Z(K-2,L-2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{(U^2+V^2)^{1/2}}{2.0*K*XR}\left[Z(K,L-2) - Z(K-2,L)\right]$$

(6) a. $$Z_p(K,L) = -\left(\frac{YSC}{XSC}\right)^2\left[Z(K+1,L-1) - 2.0*Z(K,L-1) + Z(K-1,L-1)\right]$$
$$+ 2.0*Z(K,L-1) - Z(K,L-2) - \frac{V}{K*YSC}\left[Z(K,L-1) - Z(K,L-2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{U}{2.0*K*XSC}\left[Z(K+1,L-1) - Z(K-1,L-1)\right]$$

(7) a. $$Z_p(K,L) = 4.0*Z(K+1,L-1) - Z(K+2,L) - Z(K,L-2) - Z(K+2,L-2)$$
$$- \frac{(U^2+V^2)^{1/2}}{K*XR}\left[Z(K+1,L-1) - Z(K+2,L-2)\right]$$

b. $$Z(K,L) = Z_p(K,L) - \frac{(U^2+V^2)^{1/2}}{2.0*K*XR}\left[Z(K+1,L) - Z(K,L-1)\right]$$

(8) a. $$Z_p(K,L) = -\left(\frac{XSC}{YSC}\right)^2\left[Z(K+1,L+1) - 2.0*Z(K+1,L) + Z(K+2,L)\right]$$

$$+ 2.0*Z(K+1,L) - Z(K+2,L) - \frac{U}{K*XSC}\left[Z(K+1,L) - Z(K+2,L)\right]$$

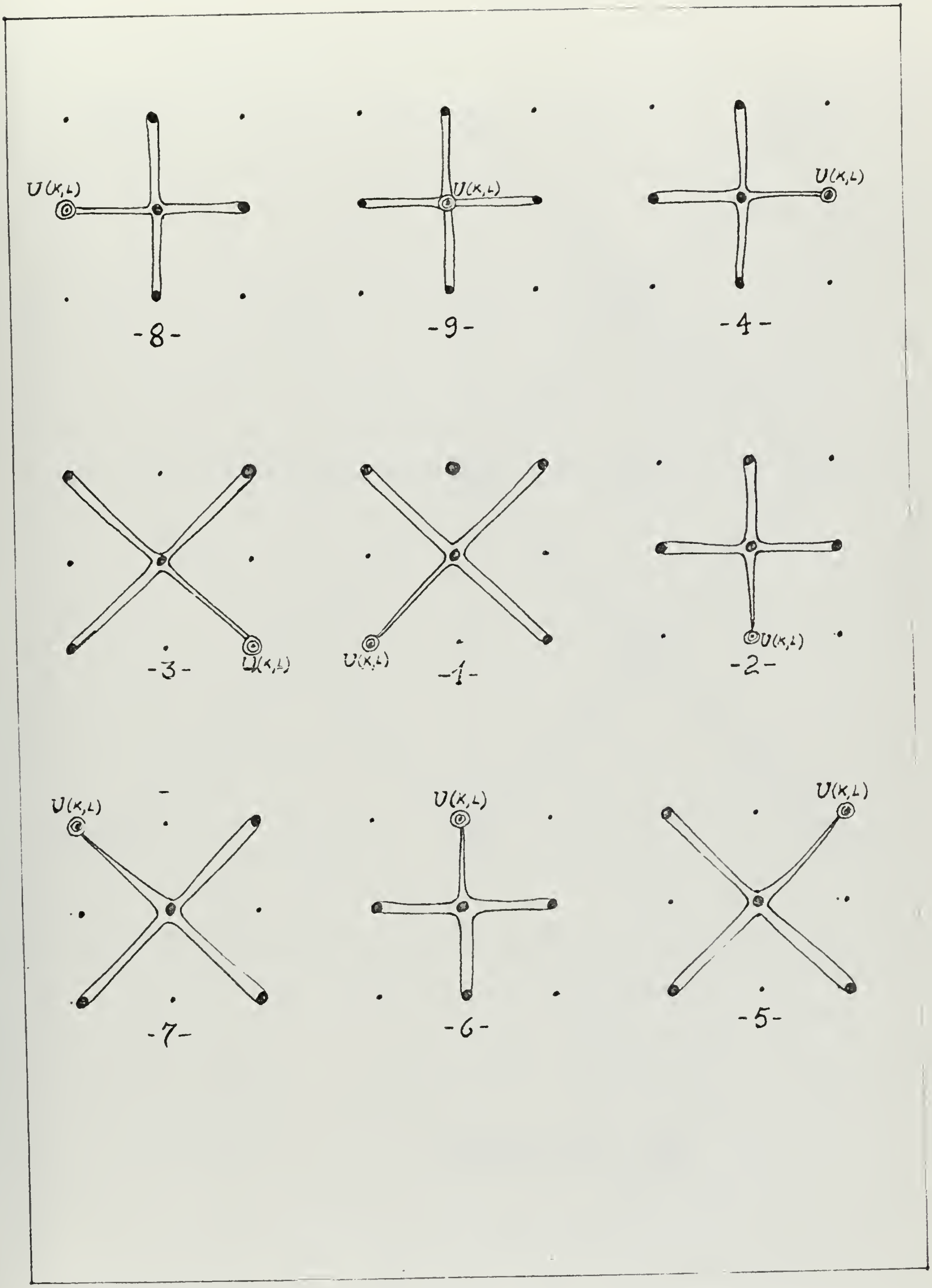
b. $$Z(K,L) = Z_p(K,L) - \frac{V}{2.0*K*YSC}\left[Z(K+1,L+1) - Z(K+1,L-1)\right]$$

(9) a. $$Z_p(K,L) = \frac{Z(K+1,L) + \left(\frac{XSC}{YSC}\right)^2\left[Z(K,L+1) + Z(K,L-1) + Z(K-1,L)\right]}{\left[2.0*\left(\frac{XSC}{YSC}\right)^2 + 2.0\right]}$$

$$Z(K,L) = Z_p(K,L) - \left[Z(K+1,L) - Z(K-1,L)\right]\frac{U}{K*2.0*XSC} +$$

b. $$\frac{V}{2.0*K*YSC}\left[Z(K,L+1) - Z(K,L-1)\right]$$

In each case the computing molecule has been divided in two parts in order to give more flexibility to the computation and be able to compute the Lapacean and the gradient separately. In order to be able to use all molecules, the X-axis scale, XSC, must be equal to the Y-axis scale, YSC. If the preceeding is not the case, local distortion may be introduced. Also the above procedures are not iterative and, therefore, stability problem will not arise.



FIRGURE 4. Sequence of rotation of the computing molecule around a grid point with no value U(K,L).

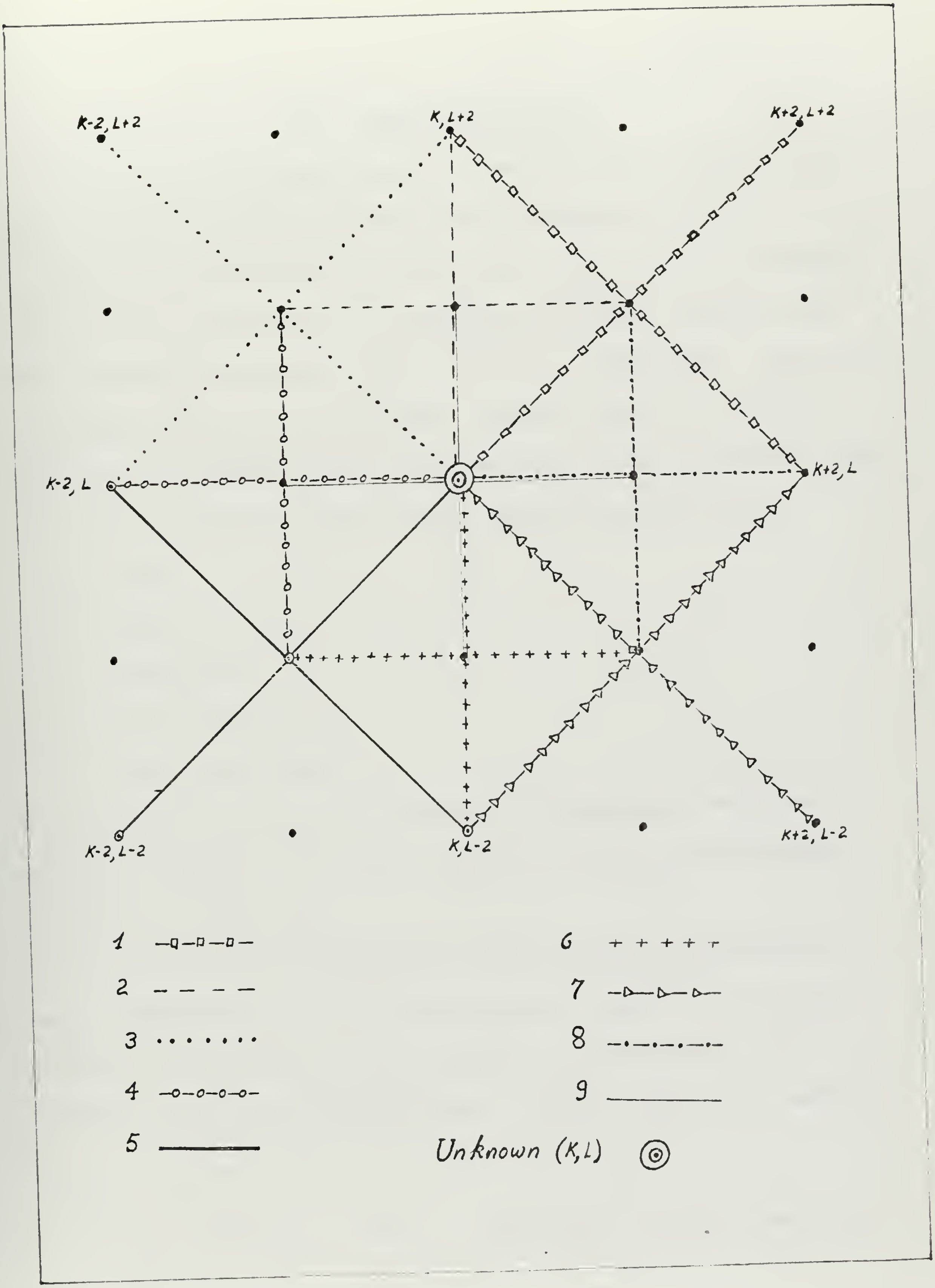


FIGURE 5. A complete rotation of the computing molecule.

III. DESCRIPTION OF DATA

In order to verify the proposed scheme, data were selected from areas with good data coverage and well known physical features.

One area considered was the California coast between San Francisco Bay and Monterey Bay and the corresponding data were obtained by the AGOR[1] cruises of September 1969 and 28 April - 4 May 1970. These data correspond to standard oceanographic stations (Figure 2). However, not all the information was readily available due to the fact that the data were reduced for specific uses. The data available were;

a. Wind

b. depth

c. temperature

d. Sound velocity

e. Beam transmittance

at observation depths only. Under these circumstances the general procedure, Equation (11), doesn't apply and therefore the modified procedure, c., was used.

A second area was considered in order to verify the objective analysis procedures at low latitudes. This second set of data was obtained by the Colombian Navy's Division of oceanography in the Caribbean sea off the Colombian coast. In this case all the data from

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[1] Cruises by ships of the U. S. Oceanographic Office under investigation plans by the Naval Postgraduate School.

a standard oceanographic station were available. However, the same simplified procedure, c., was used in order to obtain results comparable to those for the California coasts case.

IV. DISCUSSION OF RESULTS

A. COMPARISON OF OBJECTIVE AND SUBJECTIVE ANALYSIS

A subjective analysis, Shepard (1970), of sea surface temperature for the area along the California coast appears in Figure 6. Shepard performed the analysis in order to make a comparison of oceanographic parameters during upwelling. The objective analysis of the same data appears in Figure 7.

For the objective analysis, Figure 7, the grid was rotated 47 degrees in order to follow the general trend of the coast. Because the mean wind was generally along the X-axis during the cruise, an initial value of P equal -0.27 or a current 20 degrees to the right of the X-axis was selected.

A comparison clearly shows greater complexity and more details in the objective analysis than the subjective analysis. The obvious question that arises is; do these details represent artificial additions or real features with physical meaning? Also, do they represent features expected with the inherent assumption of the objective scheme?

It may be stated that subjective analysis is a linear interpolation which normally depends only on the available data for one oceanographic variable at a time. This generally excludes consideration of currents. Representations in intermediate regions with no data are generally smoothed contours. The resulting scalar field (as depicted in Figure 6) is very familiar in the oceanographic work and a departure from this picture is often viewed with suspicion. Adverse appraisal of a more

FIGURE 6. Subjective analysis of sea surface temperature for 28 April - 4 May 1970 (After Shepard 1970)

FIGURE 7. Objective analysis of sea surface temperature for April - May 1970, showing wind field. Arrows are the $\mathbf{V}/K = U/K\,\hat{i} + V/K\,\hat{j}$ vector.

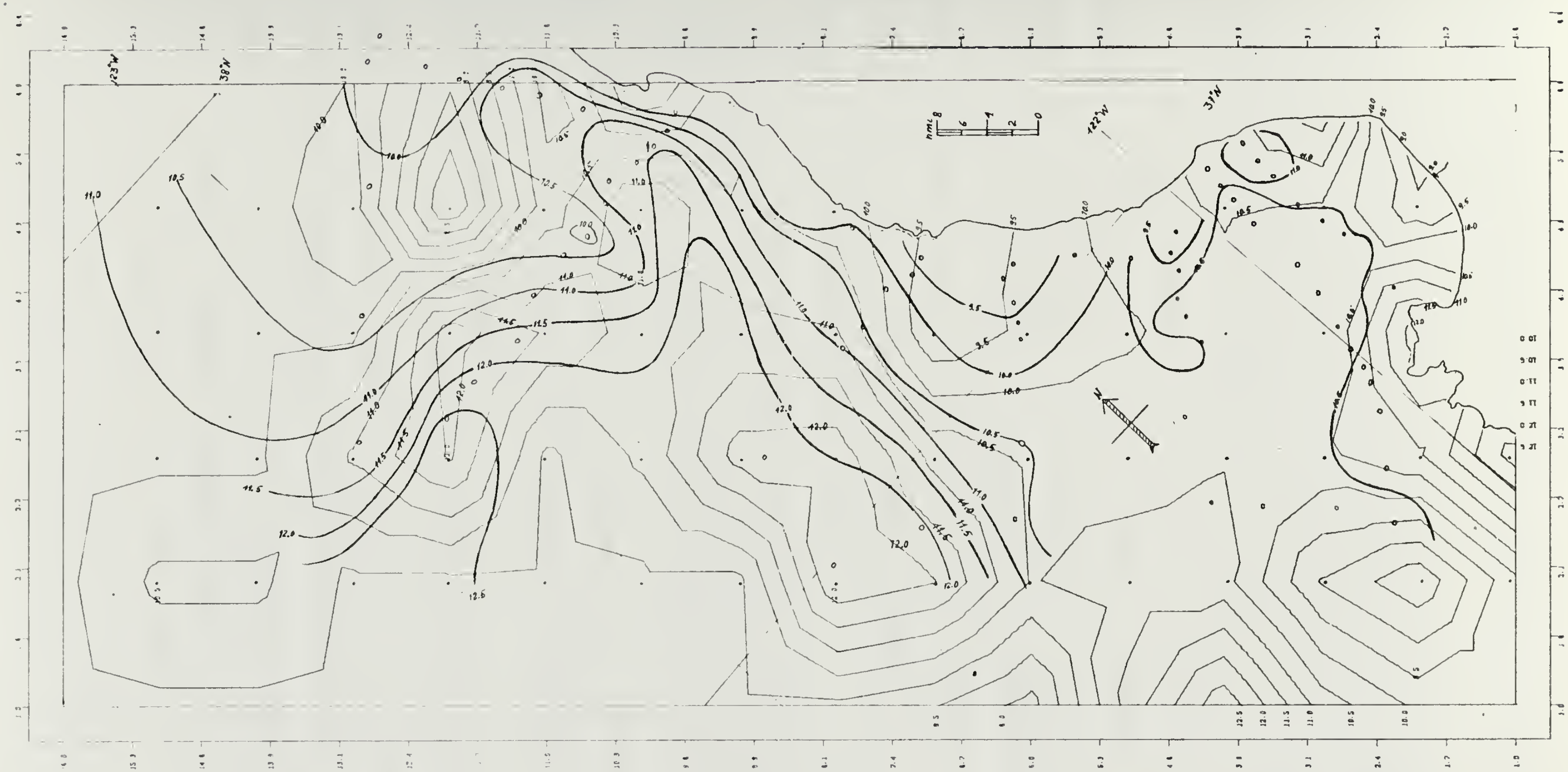

FIGURE 8. Comparison of subjective and objective analyses of sea surface temperature for California coast. 28 April-4 May 1970.

detailed representation is not totally justified as stated in the following passage:

> "Linearity between widely scattered data should not be assumed. It is a paradox of analysis that the less data the analyst has, the more the analysis show smooth curves and evenly spaced perturbations. It is only when more data are added and the presence of detailed structures becomes apparent but not entirely delineated by the data that the analysis becomes difficult." (Ocean Thermal Structure Forecasting, ASWEPS manual series, v. 5, p. 23).

Other features present in the objective and absent in the subjective analysis are the circular patterns or pools of relative warmer or cooler water. This type of temperature distribution is intuitively logical as most swimmers can tell and physically may be expected. Subjective analysis procedures are not suitable for detecting them because they do not normally involve considerations of temperature along with advection currents and diffusion terms.

> "Eddies have seldom been fully delineated. Usually a single line of temperature observations crosses what may be a roughly circular core of warmer water or a tongue of a warmer water extending back to the source." (Summary of Technical Reports of the National Defense Research Committee, v. 6A, p. 73)

The importance of including the influence of the wind action, i. e. wind currents, within the scalar analysis is emphasized further in the following physical arguments.

Wind and wave action have a net result of mass transport of water and therefore both are capable of producing zones of convergence or divergence accompanied by a rising or lowering of the thermocline or may be responsible for water of one temperature being carried over water of another. (Summary of Technical Reprots of the National Defense Research Committee, v. 6A). For example,

> "The effect of the wind in maintaining or deepening an isothermal surface layer is complicated by the fact that the wind sets up a current near the surface which may remove the mixed water from a

given area almost as fast as it is formed." (Summary of Technical Reports of the National Defense Research Committee, v. 6A, p. 42)

B. INTERPRETATION OF RESULTS IN TERMS OF THE ANALYTICAL MODEL.

Additional interpretations of the features within the objective analysis are possible by considering the basic processes included in the analytical model. The physical description of the analytical model, Equation (4), used in the objective analysis scheme is that when a steady state is reached the advection of the scalar property is equal to the eddy diffusion of the scalar in the medium. With this physical interpretation, we can explain certain features of the circular distribution of properties when these features are frozen in time (stationary). These features are:

1. Circular patterns,
2. Tongue type patterns,
3. Gradients
4. Size of closed isolines.

With respect to the circular patterns, heating and cooling of the sea surface is not uniform for the entire layer of the analysis and therefore in any event a local circulation will be generated in order to obtain the equilibrium of mass. Warm water will flow from the source toward the periphery in all directions and the Coriolis acceleration will deflect the paths to the right (in the Northern Hemisphere) until they become circular. This situation will exist as long as a disequilibrium in mass exists and will become a steady state when advection out of the circle is equal to the inflow of warm water, a similar situation is reached in a cold pool where warm water from the periphery is going to the center of the pool following a circular path.

Decaying drift currents will also produce the same effect because once the wind ceases the drift current continues to move for a certain time under its inertia while being acted upon by the Coriolis acceleration and while being damped by the diffussion term.

With respect to tongue type features, the oceanographic literature has abundant examples of tongue-like diffusion of properties such as salinity and temperature. For example, it has been observed that in areas of convergence, convection cells, the surface water moves downwind at a considerably more rapid rate than in areas of divergence and therefore the flow of water in response to the wind should be uneven.

With respect to the gradients, because vertical mass transport occurs in the convective layer, it is clear that the assumption of a horizontally homogeneous mixed layer above the thermocline is an over-simplified concept and relatively high gradients may be possible in short horizontal distances. This is especially true in the area examined which is in coastal waters, where an irregular wind field may have existed and where upwelling is known to exist. The analytical model was, of course, a non divergent and this may not have been the case. Therefore, greater than normal gradients inside the inertial circles may reflect over compensation for the upwelling or downwelling effect in the temperature. Although, this is, perhaps, an unrealistic result, it could be smoothed out by computing the amount of this effect using the grid points over nearby coastal regions (U. S. Fleet Numerical Weather Facility. Technical memo No. 5, January 1965). On the other hand, artificial intensification of the gradient may still be used to identify convergence and divergence zones by allowing a maximum gradient in a given region depending of local conditions.

With respect to the size of closed isolines, the radius of the inertial circle for the type of circulation mentioned above varies with the velocity and the sine of the latitude: For a current of average velocity located in mid-latitudes this radius is about 15 miles which can be greater if the circulation is influenced by a horizontal component of gravitational force or other lateral force (Summary of Technical Reprots of the National Defense Research Committee, v. 6A). It is interesting to note that 15 miles is the order of magnitude observed in the circular features of the objective analysis under consideration.

Therefore, it seems possible, with this analytical model, to relate circular and elliptical features to inertial currents due to differential heating and cooling, convergences, divergences, decaying wind drift currents; tongue like features to normal diffusion processes; and intensified gradients inside circular patterns to strong upwelling or downwelling. However, gradients are represented very well within the analytical model. Reasons for the latter feature are however, known.

C. COMPARISON OF OBJECTIVE ANALYSIS RESULTS FOR DIFFERENT LEVELS

In order to verify vertical consistency, a mixed layer of at least 10 meters was assumed and an objective analysis of the 10-meter level was made and is shown in Figure 9. However, the wind field was not uniform and, there was not enongh information about fetch and duration with available wind observations. Therefore, we do not expect to obtain an exact correspondence of the features of the two layers over the entire grid. Nevertheless, vertical continuity is observed when the main features of the two analyses are superimposed in Figure 10.

Maximum and minimum temperature regions are marked with letters A through K in Figure 7 and apparent corresponding features in Figure 9 have been marked with same letters with a prime sign. The same regions are shown in Figure 10 but delineated by only one or two isotherms in order to simplify the resulting picture.

The comparison of thermal structure at the two levels shows an almost identical correspondence between regions

A and A'

B and B'

D and D'

E and E'

F and F'

H and H'

I and I'

J and J'

This may be expected from good vertical mixing and more or less constant advection in the entire layer.

Regions C and C'

K and K'

G and G'

have horizontal relative displacement from 5 to 12 miles. This may be due to a different velocity field for the two levels. Past history (i. e. two or three weeks earlier) would show how these advective distortions were generated. Similar results may be obtained for the September data (Figures 11 and 12).

Considering that each analysis is completely independent from the other, this comparison shows convincing verification of vertical consistence.

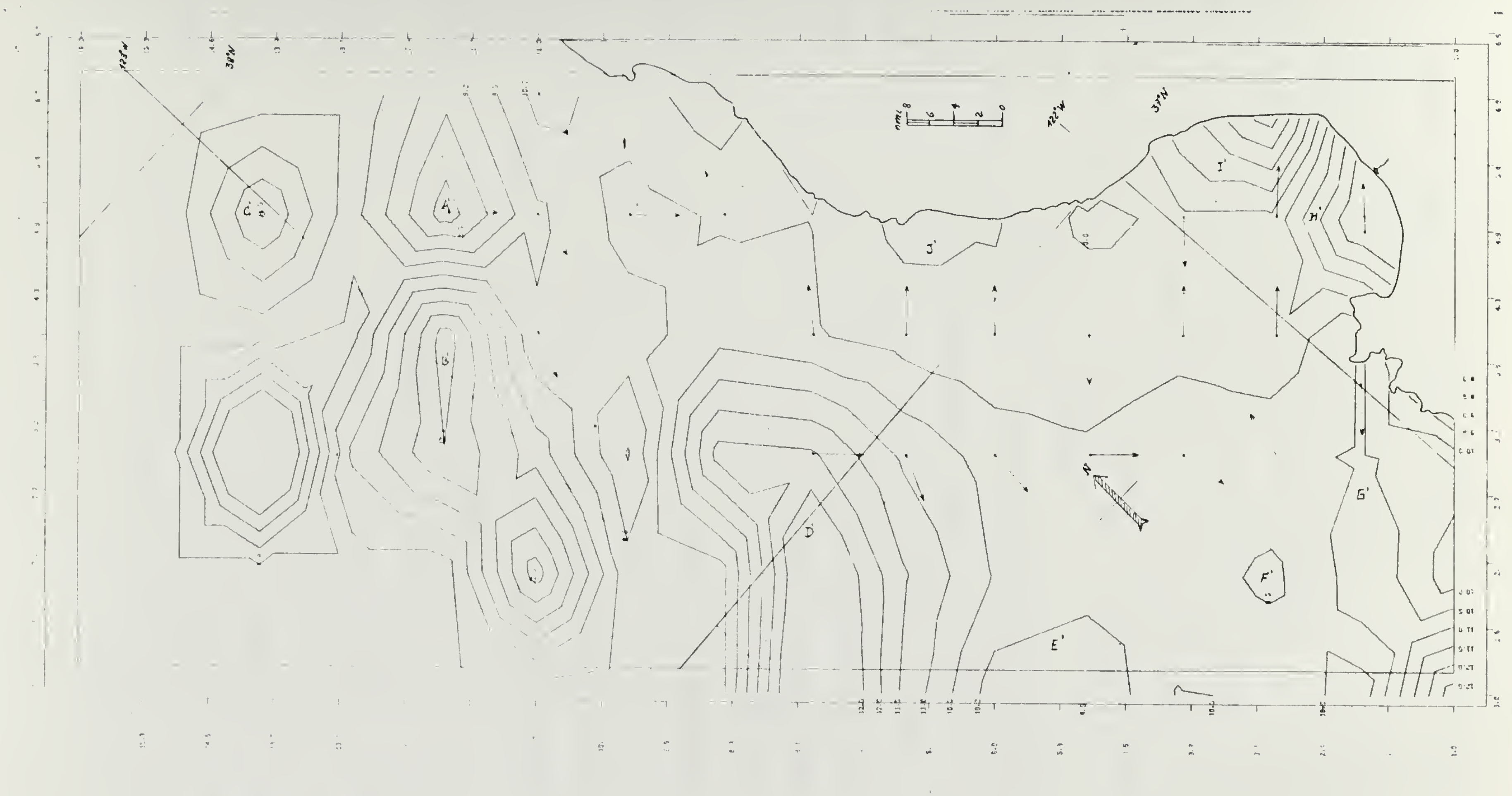

FIGURE 9. Objective analysis of temperature, California coast, at the 10-meter level for 28 April - 5 May 1970.

D. OBJECTIVE ANALYSES OF SURFACE TEMPERATURE, SALINITY AND SIGMA-T FOR LOW LATITUDES

Objective analyses of temperature, salinity and sigma-t for a region with mean latitude of 10° north appear in Figures 14, 15, and 16. The main reason for considering these analyses for a region not very well studied from the oceanographic point of view is to compare the effect of latitude in the size of those features interpreted to be inertial circles in the preceding discussions.

The region of California coast considered has a mean latitude of 37° north and feature A in Figure 7 appears to be representative one for this region. It is observed that its mean radius is about 8 nautical miles. The radius of inertial circles is inversely proportional to the sine of the latitude and therefore it would be expected that the radius of the inertial circle be increased by a factor of approximately 3.4 when translated from latitude 37°N. to 10°N. a corresponding feature in Figure 14 was marked A" has mean radius of about 35 nautical miles. Therefore, the test for latitude effect seems satisfactory from this gross comparison. However, more precise computations would be required before a conclusive result may be obtained.

The region off the Colombian coast, considered in the low latitude study (Figure 13), receives the run-off of three main rivers: the Atrato in the south-west region of the grid and the Sinu and Magdalena rivers in the east. Features L,M and N in Figure 15 correspond to places where the run off occurs. The patterns observed at these points coincide very well with what may be expected and are very well correlated with the sigma-t distribution, L', M' and N' in Figure 16.

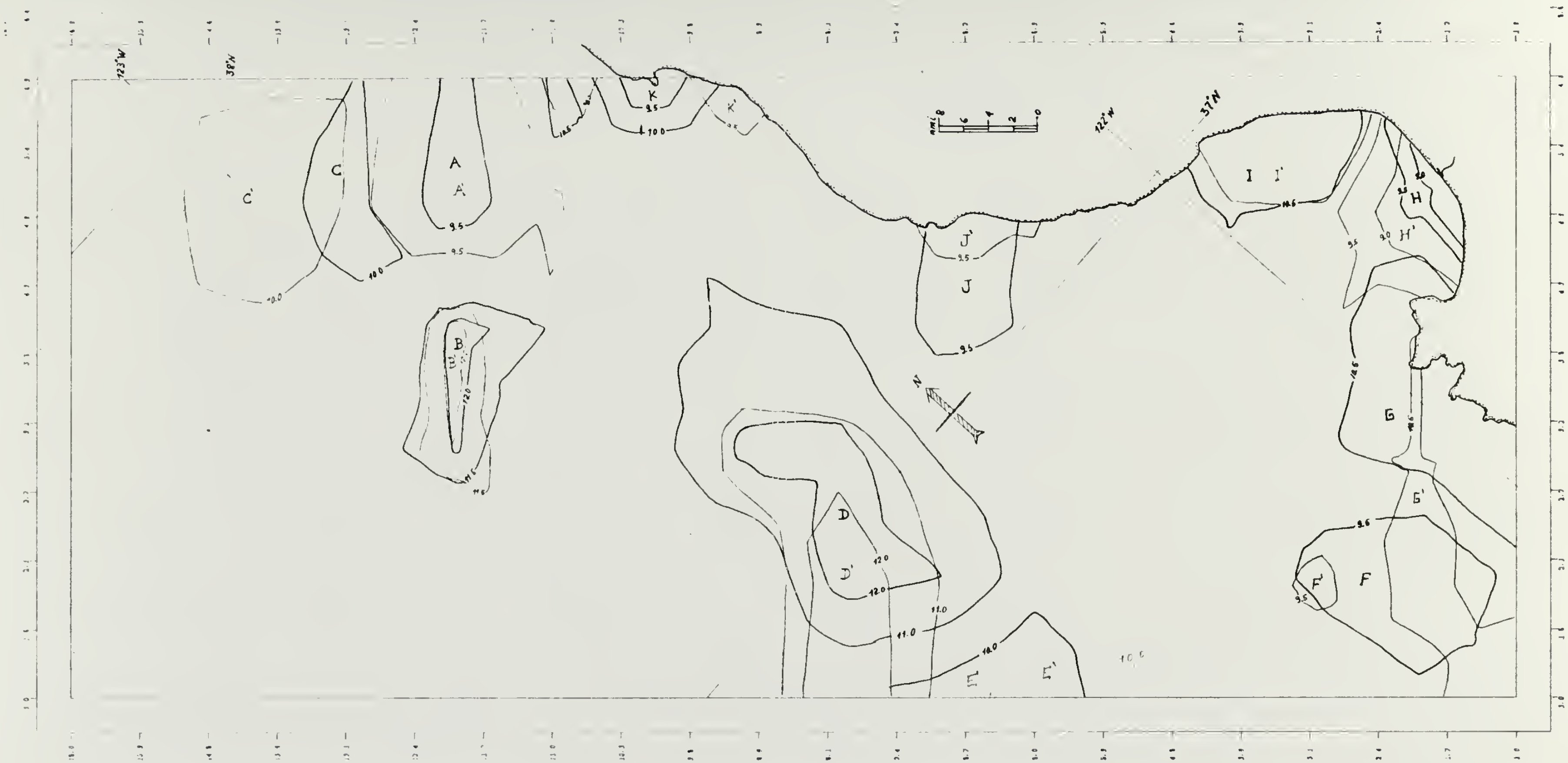

FIGURE 10. Superposition of main features from surface and 10-meter level analyses, California coast. Thin lines correspond to 10-meter level.

FIGURE 11. Objective analysis of sea surface temperature, California coast, for September 1969

FIGURE 12. Objective analysis of temperature at the 10-meter level, California coast, for September 1969

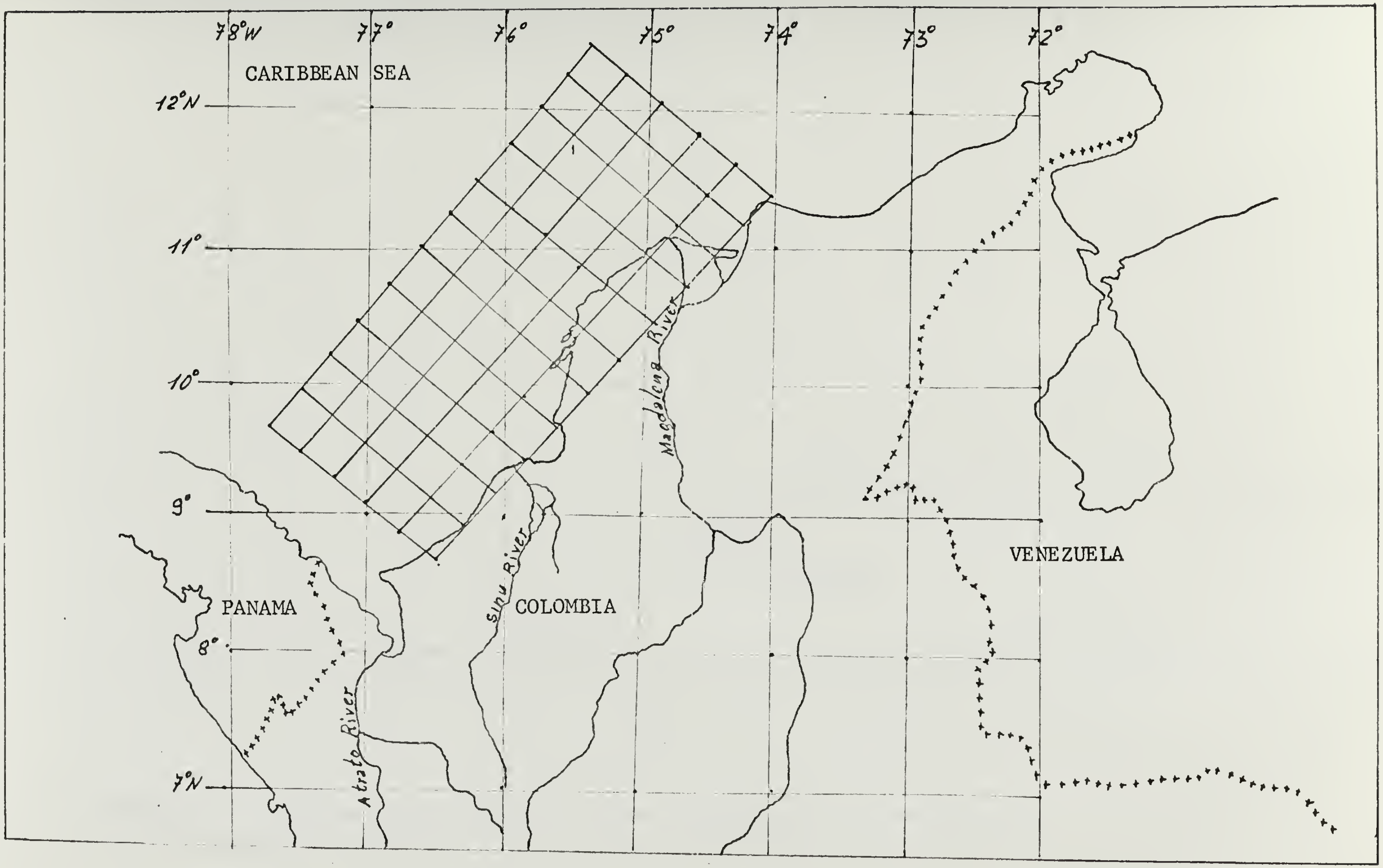

FIGURE 13. Geographic position of the grid for the Low Latitude Analysis

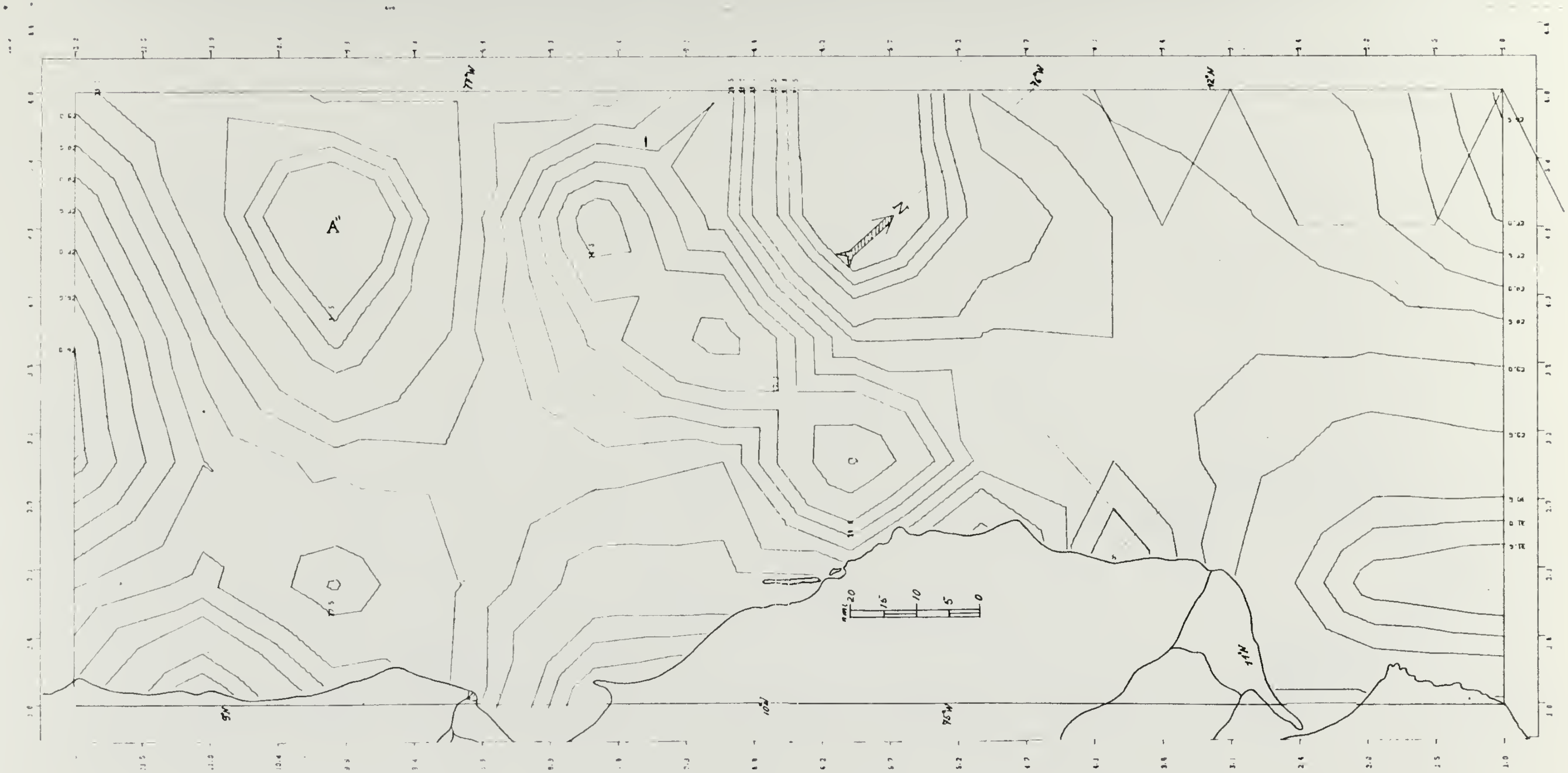

FIGURE 14. Objective analysis of sea surface temperature for low Latitude.

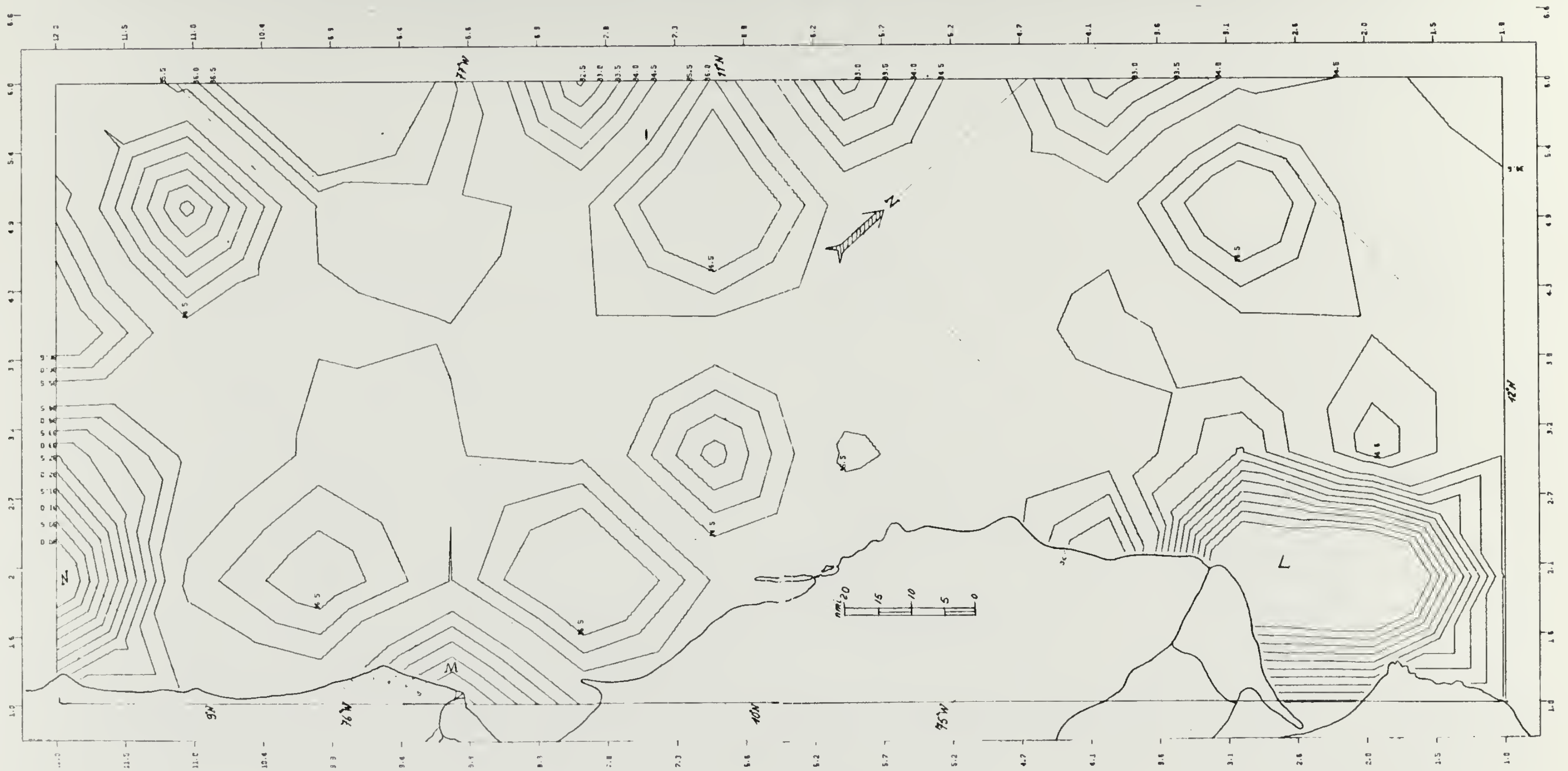

FIGURE 15. Objective analysis of sea surface salinity for low Latitude.

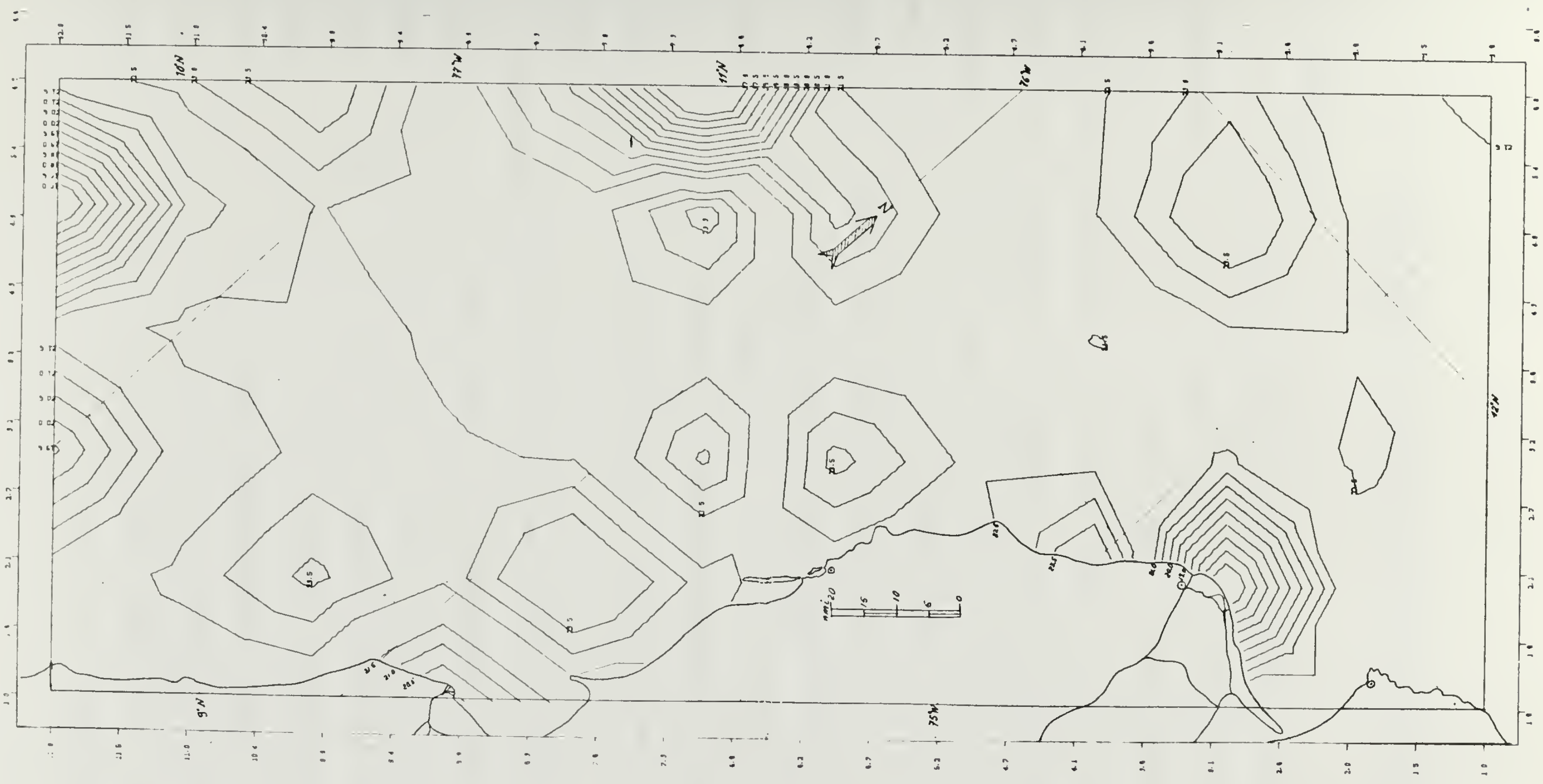

FIGURE 16. Objective analysis of sea surface sigma-T for low latitude.

V. CONCLUSIONS AND SUGGESTION FOR FUTURE RESEARCH

A. CONCLUSIONS

A small scale, high resolution and low computing time objective analysis model has been developed. More tests and field verification are required to show all of its advantages and shortcomings but tests described and interpreted in this study suggest that it has great possibilities to become a basic step in forecasting oceanographic parameters on a tactical unit level. One desirable feature of the results was the detail obtained in contrast with that obtained in a subjective analysis. The required input and simplicity enables it to be used to obtain an almost instantaneous analysis during an oceanographic survey and therefore to investigate interesting features not foreseen in planning stages. Therefore, it could be applied for the purposes of reducing costs and increasing scientific results of an oceanographic expedition.

The procedures described need to be refined in order to allow for convergence or divergence whenever these phenomena become important. However, by understanding how the analytical model (section B) handles these features, meaningful interpretations can be made even for these features in the results. The data should be corrected for diurnal effects but there is not a satisfactory procedure for this (Technical report, ASWEPS No. 13). An alternative solution, observations at the same hour of the day, may be undertaken by XBT drops. This is perhaps, unfeasible at most oceanographic stations due to operational costs.

B. SUGGESTIONS FOR FUTURE RESEARCH

A suggestion for future investigation would be to integrate this scheme into a forecast procedure. The following steps could be applied using the present form of the scheme:

a. Objective analysis using horizontal grid at standard depths.

b. Conversion to a three-dimensional grid using the vertical grid as a complementary tool.

c. Repetition of procedures a. and b. at equally spaced time steps.

d. Determination of Lagrangian time rate of change for identificable. structures (assuming that some of them are persistent in relation to the time step selected as seems to be the case in the neighborhood of constant currents).

e. Determination of changes in the heat budget for each characteristic structure and (relating) it to easily measured parameters such as amount of clouds in each standard level, sun's declination (season) and hour of the day.

f. Measurement of advection by means of changes in the structures in point d. and (relating) it to permanent currents, wind speed, direction and duration.

g. Forecast for the next time step.

h. Forecast verification and obtention of corrective cefficients.

In the delineation of the steps leading to a forecast it has been assumed that some features may have a relative long duration or persistence but this situation must be investigated for each application. If it is proved, identification of persistent or semipersistent features, their changes in time and parameters affecting them may be a simple approach for detailed forecasts, even for handling transient thermoclines now practically impossible to forecast.

PROGRAM OUTPUT

28 April - 4 May

MESH	MINIMUM	MAXIMUM	MEAN LAT
2	6.000	14.000	37.000

ROTATION	PARAM	GRID	INT	INITIAL	INCREMENT	EPSILON
47.00	1	1	10	8.000	0.500	0.001

POSITION OF THE GRID REFERENCE POINT

LATITUDE		LONGITUDE	
37	43.200	124	6.000

OCEANOGRAPHIC STATIONS

LATITUDE		LONGITUDE		DEPTH	TEMP	SOUND VELOC	
36	40.50	121	53.40	0.0	11.64	1493.20	0.0
36	46.50	121	54.30	0.0	10.28	1488.50	0.0
36	47.50	121	54.30	0.0	10.31	1488.70	0.0
36	49.80	121	54.50	0.0	10.62	1489.80	0.0
36	52.90	121	54.10	0.0	11.31	1492.10	0.0
36	54.10	121	54.40	0.0	11.07	1491.20	0.0
36	55.70	121	54.40	0.0	11.02	1491.10	0.0
36	53.50	121	59.40	1.00	10.27	1488.70	0.0
36	51.80	121	59.10	0.0	9.91	1487.40	0.0
36	56.20	121	59.30	0.0	10.82	1490.30	6.50
36	54.80	121	59.10	0.0	10.53	1489.40	12.90
36	47.10	121	58.40	0.0	9.93	1487.50	27.70
36	45.30	121	58.70	0.0	10.03	1487.80	29.70
36	42.60	121	59.40	0.0	10.09	1487.90	22.30
36	41.20	121	59.20	0.0	10.43	1489.10	20.20
36	39.40	121	59.20	0.0	10.60	1489.70	24.20
36	38.20	121	59.10	0.0	10.75	1490.50	14.40
36	36.00	122	1.60	0.0	11.37	1492.40	5.60
36	33.60	122	4.60	0.0	11.04	1491.20	12.60
36	31.30	122	7.00	0.0	10.07	1487.60	64.90
36	35.30	122	10.70	0.0	10.39	1488.30	53.90
36	39.70	122	15.20	0.0	10.41	1488.70	48.50
36	42.70	122	18.70	0.0	9.98	1487.40	63.00
36	47.00	122	14.70	0.0	10.12	1487.70	71.70
36	50.00	122	10.20	0.0	10.53	1489.40	79.10
36	51.60	122	9.70	0.0	10.25	1488.30	54.00
36	53.30	122	9.20	0.0	10.65	1489.00	26.50
36	54.30	122	7.50	1.00	10.86	1490.60	9.70
36	55.70	122	6.30	0.0	11.40	1492.70	5.10
36	55.90	122	4.80	0.0	11.24	1491.90	5.70
37	0.40	122	14.30	0.0	9.62	1487.30	21.40
37	3.80	122	17.90	0.0	9.55	1486.70	22.50
37	4.20	122	19.40	0.0	9.49	1486.50	23.00
36	57.40	122	10.00	0.0	11.42	1486.30	7.60
37	2.70	122	20.50	0.0	9.38	1486.30	36.00
37	1.50	122	21.80	0.0	9.56	1486.90	33.20
37	0.10	122	23.30	0.0	9.70	1487.40	26.80
36	59.40	122	24.00	1.00	9.85	1487.90	19.30
36	56.30	122	28.60	0.0	10.41	1489.60	0.0
36	53.20	122	33.40	0.0	10.48	1489.70	18.40
36	58.40	122	40.50	0.0	12.04	1494.40	65.90
37	2.60	122	48.40	0.0	12.45	1495.70	62.90
37	10.00	122	45.80	0.0	12.22	1495.00	66.50
37	10.00	122	41.80	0.0	12.33	1495.30	63.50
37	11.00	122	38.50	0.0	11.70	1493.30	62.70
37	10.90	122	35.20	0.0	11.21	1492.60	9.50
37	11.00	122	33.20	0.0	10.81	1489.90	9.60
37	11.00	122	29.10	0.0	10.21	1489.20	10.20
37	10.40	122	26.70	0.0	9.85	1487.90	16.20

37	10.90	122	25.20	1.00	9.35	1486.00	28.80
37	15.80	122	27.50	0.0	10.26	1489.40	11.00
37	21.60	122	31.70	0.0	10.54	1490.20	9.50
37	31.90	122	33.40	0.0	9.92	1494.30	19.80
37	31.60	122	35.20	0.0	11.12	1492.30	4.10
37	32.10	122	37.10	0.0	11.65	1495.60	5.00
37	31.90	122	38.70	0.0	11.35	1492.30	5.30
37	32.20	122	41.30	0.0	11.41	1492.60	22.10
37	31.90	122	43.10	0.0	11.18	1492.50	31.80
37	31.60	122	46.90	0.0	9.76	1486.20	62.30
37	32.00	122	49.90	0.0	10.49	1489.60	63.10
37	32.30	122	54.50	0.0	10.98	1491.20	61.20
37	31.20	122	58.00	0.0	11.88	1493.90	68.20
37	32.30	123	3.80	0.0	12.27	1495.10	72.60
37	32.40	123	9.30	0.0	12.06	1494.40	63.80
37	36.80	123	15.40	0.0	11.07	1491.60	64.70
37	42.20	123	7.70	0.0	10.46	1489.40	77.20
37	47.70	122	59.70	0.0	10.19	1489.20	6.10
37	52.60	122	52.50	0.0	9.94	1488.30	12.00
37	53.20	122	49.20	0.0	9.94	1488.30	9.80
37	49.00	122	48.80	0.0	9.58	1487.00	17.70
37	46.40	122	46.90	0.0	8.95	1484.60	49.60
37	43.50	122	44.50	0.0	10.71	1490.30	16.00
37	40.20	122	42.10	0.0	10.81	1490.00	19.10
37	37.50	122	40.20	0.0	10.80	1490.30	23.00
37	37.30	123	36.60	0.0	10.62	1489.50	18.10

RELATIVE POSITION IN THE GRID

X	Y	PARAMETER
118.091	34.677	11.640
113.213	38.244	10.280
112.482	38.926	10.310
110.691	40.378	10.620
108.642	42.727	11.310
107.601	43.370	11.070
106.431	44.461	11.020
105.316	40.040	10.270
106.722	39.056	9.910
103.396	41.940	10.820
104.529	41.102	10.530
110.541	36.259	9.930
111.693	34.856	10.030
113.286	32.605	10.090
114.419	31.767	10.430
115.735	30.539	10.600
116.667	29.779	10.750
116.914	26.818	11.370
117.035	23.429	11.040
117.409	20.459	10.070
112.468	21.026	10.390
106.799	21.399	10.410
102.698	21.401	9.980
101.733	26.671	10.120
101.991	31.345	10.530
101.094	32.729	10.250
100.123	34.180	10.600
100.318	35.855	10.860
99.948	37.511	11.400
100.619	38.523	11.240
92.153	36.044	9.620
87.705	36.261	9.550
86.595	35.658	9.490
96.689	36.510	11.420
87.093	33.992	9.380
87.262	32.414	9.560
87.469	30.583	9.700
87.599	29.697	9.850
87.360	24.896	10.410
87.012	19.978	10.480
79.341	19.378	12.040
71.966	17.629	12.450
67.971	24.195	12.220
70.150	26.531	12.300
71.217	29.141	11.700
73.088	31.030	11.210
74.104	32.236	10.810
76.338	34.631	10.210
78.084	35.623	9.850
78.536	36.840	9.350
73.700	38.839	10.260
67.170	40.343	10.540
58.712	46.376	9.920
57.951	45.120	11.120
56.550	44.351	11.650
55.825	43.280	11.350
54.189	41.966	11.410
53.428	40.710	11.180
51.577	38.286	9.760
49.650	36.807	10.490
46.924	34.325	10.980
45.822	31.530	11.880
41.858	28.893	12.270
38.788	25.749	12.060

32.247	25.188	11.070
32.494	33.368	10.460
32.830	41.792	10.190
33.170	49.340	9.940
34.529	51.676	9.940
37.818	49.045	9.580
40.754	48.381	8.950
44.183	47.805	10.710
47.903	46.956	10.810
50.913	46.224	10.800
20.332	13.147	10.620

INTERPOLATED VALUES FOR THE GRID

X	Y	PARAMETER
8.00000	8.00000	0.0
16.00000	8.00000	0.0
24.00000	8.00000	0.0
32.00000	8.00000	0.0
40.00000	8.00000	0.0
48.00000	8.00000	0.0
56.00000	8.00000	0.0
64.00000	8.00000	0.0
72.00000	8.00000	0.0
80.00000	8.00000	0.0
88.00000	8.00000	0.0
96.00000	8.00000	0.0
104.00000	8.00000	0.0
112.00000	8.00000	0.0
120.00000	8.00000	0.0
128.00000	8.00000	0.0
8.00000	16.00000	0.0
16.00000	16.00000	10.62000
24.00000	16.00000	10.62000
32.00000	16.00000	0.0
40.00000	16.00000	0.0
48.00000	16.00000	0.0
56.00000	16.00000	0.0
64.00000	16.00000	0.0
72.00000	16.00000	12.45000
80.00000	16.00000	12.04000
88.00000	16.00000	10.48000
96.00000	16.00000	0.0
104.00000	16.00000	0.0
112.00000	16.00000	8.95623
120.00000	16.00000	0.0
128.00000	16.00000	0.0
8.00000	24.00000	0.0
16.00000	24.00000	0.0
24.00000	24.00000	0.0
32.00000	24.00000	11.07000
40.00000	24.00000	12.06000
48.00000	24.00000	0.0
56.00000	24.00000	0.0
64.00000	24.00000	12.22000
72.00000	24.00000	12.30000
80.00000	24.00000	0.0
88.00000	24.00000	10.41000
96.00000	24.00000	0.0
104.00000	24.00000	10.47429
112.00000	24.00000	10.39000
120.00000	24.00000	10.91652
128.00000	24.00000	0.0
8.00000	32.00000	0.0
16.00000	32.00000	0.0
24.00000	32.00000	0.0
32.00000	32.00000	2.05547
40.00000	32.00000	12.27000
48.00000	32.00000	11.43289
56.00000	32.00000	0.0
64.00000	32.00000	11.14965
72.00000	32.00000	11.02377
80.00000	32.00000	9.05577
88.00000	32.00000	9.63905
96.00000	32.00000	9.92117
104.00000	32.00000	10.33595
112.00000	32.00000	9.84487
120.00000	32.00000	12.34712
128.00000	32.00000	0.0

8.00000	40.00000	0.0
16.00000	40.00000	0.0
24.00000	40.00000	0.0
32.00000	40.00000	10.19000
40.00000	40.00000	0.0
48.00000	40.00000	10.26933
56.00000	40.00000	11.43151
64.00000	40.00000	10.54000
72.00000	40.00000	10.26000
80.00000	40.00000	9.35000
88.00000	40.00000	9.55000
96.00000	40.00000	0.0
104.00000	40.00000	10.54430
112.00000	40.00000	10.45130
120.00000	40.00000	0.0
128.00000	40.00000	0.0
8.00000	48.00000	0.0
16.00000	48.00000	0.0
24.00000	48.00000	0.0
32.00000	48.00000	10.00981
40.00000	48.00000	8.11982
48.00000	48.00000	10.72071
56.00000	48.00000	8.92048
64.00000	48.00000	10.39016
72.00000	48.00000	0.0
80.00000	48.00000	0.0
88.00000	48.00000	0.0
96.00000	48.00000	0.0
104.00000	48.00000	11.02000
112.00000	48.00000	12.20851
120.00000	48.00000	0.0
128.00000	48.00000	0.0

U/K	V/K	RATIO	K	L
0.600	0.0	0.600	10	2
0.600	0.0	0.600	11	2
0.006	-0.600	0.600	12	2
0.600	0.0	0.600	13	2
0.600	0.0	0.600	14	2
0.600	0.0	0.600	9	3
0.600	0.0	0.600	10	3
0.591	-0.102	0.600	11	3
0.600	0.0	0.600	12	3
-0.033	0.599	0.600	13	3
0.600	0.0	0.600	14	3
0.600	0.0	0.600	15	3
0.600	0.0	0.600	7	4
-0.374	0.469	0.600	8	4
0.600	0.0	0.600	9	4
0.600	0.0	0.600	10	4
-0.155	0.580	0.600	11	4
0.192	-0.569	0.600	12	4
0.600	0.0	0.600	13	4
0.600	0.0	0.600	14	4
0.600	0.0	0.600	5	5
0.600	0.0	0.600	6	5
0.600	0.0	0.600	7	5
0.547	-0.246	0.600	8	5
0.546	-0.249	0.600	9	5
0.600	0.0	0.600	10	5
0.600	0.0	0.600	11	5
0.600	0.0	0.600	12	5
-0.064	0.597	0.600	13	5
0.600	0.0	0.600	14	5
0.600	0.0	0.600	15	5
0.600	0.0	0.600	8	6
0.600	0.0	0.600	9	6
0.600	0.0	0.600	10	6
0.600	0.0	0.600	11	6
0.600	0.0	0.600	12	6
0.600	0.0	0.600	13	6
0.600	0.0	0.600	14	6

FINAL VALUES FOR GRID POINTS

TEMP	K	L
9.89	1	1
9.89	2	1
9.89	3	1
9.89	4	1
9.89	5	1
9.89	6	1
9.89	7	1
9.89	8	1
9.89	9	1
9.64	10	1
8.79	11	1
11.05	12	1
12.88	13	1
11.46	14	1
9.89	15	1
9.89	16	1
9.89	1	2
10.62	2	2
10.62	3	2
9.89	4	2
9.89	5	2
9.89	6	2
9.89	7	2
9.89	8	2
12.45	9	2
12.04	10	2
10.48	11	2
10.66	12	2
10.81	13	2
8.96	14	2
7.98	15	2
9.89	16	2
9.89	1	3
9.89	2	3
9.89	3	3
11.07	4	3
12.06	5	3
9.89	6	3
10.61	7	3
12.22	8	3
12.30	9	3
10.89	10	3
10.41	11	3
10.34	12	3
10.47	13	3
10.39	14	3
10.92	15	3
12.90	16	3
9.89	1	4
9.89	2	4
9.89	3	4
9.89	4	4
12.27	5	4
11.43	6	4
10.75	7	4
11.15	8	4
11.02	9	4
9.06	10	4
9.64	11	4
9.92	12	4
10.34	13	4
9.84	14	4
12.35	15	4
9.89	16	4

9.89	1	5
9.89	2	5
9.89	3	5
10.19	4	5
7.51	5	5
10.27	6	5
11.43	7	5
10.54	8	5
10.26	9	5
9.35	10	5
9.55	11	5
10.38	12	5
10.54	13	5
10.45	14	5
9.30	15	5
6.45	16	5
9.89	1	6
9.89	2	6
9.89	3	6
10.01	4	6
8.12	5	6
10.72	6	6
8.92	7	6
10.39	8	6
10.10	9	6
8.57	10	6
11.01	11	6
10.13	12	6
11.02	13	6
12.21	14	6
8.03	15	6
9.89	16	6

PROGRAM OUTPUT

MESH	MINIMUM	MAXIMUM	MEAN LAT
2	6.000	14.000	37.000

28 April - 4 May

ROTATION	PARAM	GRID	INT	INITIAL	INCREMENT	EPSILON
47.00	1	1	10	8.000	0.500	0.001

POSITION OF THE GRID REFERENCE POINT

LATITUDE		LONGITUDE	
37	43.200	124	6.000

OCEANOGRAPHIC STATIONS

LATITUDE		LONGITUDE		DEPTH	TEMP	SOUND VELOC	
36	40.50	121	53.70	10.00	10.61	1490.00	0.0
36	42.20	121	54.70	11.00	10.51	1489.40	0.0
36	43.80	121	54.60	11.00	9.76	1487.00	0.0
36	45.00	121	54.30	10.00	10.28	1488.80	0.0
36	46.50	121	54.30	9.00	10.27	1488.60	0.0
36	47.50	121	54.30	11.00	10.03	1487.80	0.0
36	49.80	121	54.50	9.00	10.58	1489.80	0.0
36	51.40	121	54.30	10.00	11.03	1491.30	0.0
36	52.90	121	54.10	11.00	11.18	1491.90	0.0
36	54.10	121	54.40	9.00	11.08	1491.50	0.0
36	55.70	121	54.40	9.00	11.01	1491.20	0.0
36	56.20	121	59.30	9.00	10.63	1489.90	0.0
36	54.80	121	59.10	10.00	10.42	1489.20	0.0
36	53.50	121	59.40	10.00	9.85	1487.30	0.0
36	51.80	121	59.10	10.00	9.78	1486.90	0.0
36	47.10	121	58.40	10.00	9.63	1486.40	0.0
36	45.30	121	58.70	10.00	9.60	1486.30	0.0
36	44.30	121	59.10	11.00	9.87	1487.20	0.0
36	42.60	121	59.40	10.00	10.08	1488.10	0.0
36	41.20	121	59.20	11.00	10.41	1489.20	0.0
36	39.40	121	59.20	12.00	10.63	1489.90	0.0
36	38.20	121	59.10	10.00	10.51	1488.60	0.0
36	36.00	122	1.60	11.00	10.47	1488.80	0.0
36	33.60	122	4.60	8.00	11.07	1491.40	0.0
36	31.30	122	7.00	10.00	10.00	1487.60	0.0
36	35.30	122	10.70	8.00	10.38	1488.50	0.0
36	39.70	122	15.20	10.00	10.45	1488.90	0.0
36	42.70	122	18.70	10.00	9.98	1487.40	0.0
36	47.00	122	14.70	10.00	9.89	1486.90	0.0
36	50.00	122	10.20	7.00	9.48	1485.80	0.0
36	51.60	122	9.70	8.00	9.77	1486.70	0.0
36	53.30	122	9.20	9.00	10.14	1488.30	0.0
36	54.30	122	7.50	11.00	9.40	1485.40	0.0
36	55.70	122	6.30	11.00	9.70	1487.10	0.0
36	55.90	122	4.80	10.00	10.39	1488.70	0.0
37	0.40	122	14.30	10.00	9.33	1486.50	0.0
37	3.80	122	17.90	8.00	9.47	1486.70	0.0
37	4.20	122	19.40	7.00	9.39	1486.20	0.0
37	2.70	122	20.50	8.00	9.36	1486.40	0.0
37	31.40	122	21.80	9.00	9.29	1486.00	0.0
37	33.10	122	23.30	9.00	9.63	1487.10	0.0
37	0.10	122	23.30	9.00	9.60	1487.10	0.0
36	59.40	122	24.00	11.00	9.84	1488.20	0.0
36	56.30	122	28.60	8.00	10.28	1489.60	0.0
36	53.20	122	33.40	9.00	10.46	1489.80	0.0
36	58.40	122	40.50	9.00	11.57	1493.20	0.0
37	32.60	122	48.40	10.00	12.45	1495.80	0.0
37	10.00	122	45.80	10.00	12.23	1475.20	0.0
37	10.00	122	41.80	9.00	12.10	1494.70	0.0

00	122	38.50	9.00	11.18	1491.80	0.0
90	122	35.20	10.00	10.27	1489.30	0.0
00	122	33.20	11.00	10.57	1490.50	0.0
30	122	31.30	10.00	9.10	1485.80	0.0
00	122	29.10	9.00	10.09	1488.90	0.0
40	122	26.70	10.00	9.49	1486.60	0.0
90	122	25.20	10.00	9.32	1486.20	0.0
80	122	27.50	9.00	10.05	1488.80	0.0
60	122	29.60	9.00	9.87	1488.10	0.0
70	122	31.70	10.00	9.51	1486.70	0.0
90	122	33.40	8.00	8.98	1485.60	0.0
60	122	35.20	9.00	9.32	1485.90	0.0
10	122	37.10	8.00	9.78	1487.10	0.0
90	122	38.70	11.00	9.52	1486.80	0.0
20	122	41.30	11.00	9.73	1487.40	0.0
90	122	43.10	9.00	10.59	1490.60	0.0
60	122	46.90	10.00	9.75	1487.40	0.0
00	122	49.90	9.00	10.46	1489.70	0.0
30	122	54.50	9.00	10.91	1491.30	0.0
20	122	58.00	9.00	11.04	1491.40	0.0
30	123	3.80	9.00	12.25	1495.30	0.0
40	123	9.30	8.00	11.98	1494.30	0.0
80	123	15.40	10.00	10.61	1490.30	0.0
20	123	7.70	11.00	9.36	1485.40	0.0
70	122	59.70	10.00	9.65	1487.30	0.0
60	122	52.50	10.00	9.95	1488.40	0.0
20	122	49.20	8.00	9.92	1488.40	0.0
00	122	48.80	10.00	9.44	1486.40	0.0
40	122	46.90	9.00	8.93	1484.80	0.0
50	122	44.50	9.00	10.22	1488.80	0.0
20	122	42.10	10.00	9.82	1487.90	0.0

FINAL VALUES FOR GRID POINTS

TEMP	K	L
9.70	1	1
9.70	2	1
9.70	3	1
9.70	4	1
9.70	5	1
9.70	6	1
9.70	7	1
9.70	8	1
13.42	9	1
11.84	10	1
10.32	11	1
8.79	12	1
7.62	13	1
8.09	14	1
8.28	15	1
9.70	16	1
9.70	1	2
9.70	2	2
9.70	3	2
9.70	4	2
9.70	5	2
12.77	6	2
9.70	7	2
9.70	8	2
12.83	9	2
11.57	10	2
10.46	11	2
9.65	12	2
9.32	13	2
9.23	14	2
11.75	15	2
9.70	16	2
9.70	1	3
9.70	2	3
6.10	3	3
10.61	4	3
11.98	5	3
10.78	6	3
9.03	7	3
12.23	8	3
12.10	9	3
11.09	10	3
10.28	11	3
9.98	12	3
10.40	13	3
10.38	14	3
10.55	15	3
9.51	16	3
9.70	1	4
9.70	2	4
9.70	3	4
9.36	4	4
12.25	5	4
9.57	6	4
9.80	7	4
10.29	8	4
10.05	9	4
10.42	10	4
9.59	11	4
9.59	12	4
9.81	13	4
9.61	14	4
10.54	15	4
6.98	16	4

9.70	1	5
9.70	2	5
11.61	3	5
9.65	4	5
7.67	5	5
9.38	6	5
10.20	7	5
9.86	8	5
9.92	9	5
9.32	10	5
9.47	11	5
10.14	12	5
9.89	13	5
9.86	14	5
7.20	15	5
8.26	16	5
9.70	1	6
9.70	2	6
9.70	3	6
9.90	4	6
8.26	5	6
10.19	6	6
9.76	7	6
9.14	8	6
10.46	9	6
7.49	10	6
10.63	11	6
7.64	12	6
11.01	13	6
12.64	14	6
8.10	15	6
9.70	16	6

PROGRAM FOR OBJECTIVE ANALYSIS OF CONSERVATIVE PARAMETERS OF THE OCEAN

```
      REAL*8 TITLE
      LOGICAL*1 LTG
      COMMON/OBS/XO(120),YO(120),OBS1(120)
      COMMON/GRID/GVAL1(50,50)
      CCMMON/DATA/LAT(100),OMINL(100),LONG(100),OMING(100),
     2DEPTH(100),OB1(100),OB2(100),OB3(100)
      COMMON/PARAM/X(20),Y(20),Z(20)
      DIMENSION CL(10),LTG(3),TITLE(12)
      DIMENSION G(50,50)
C PROGRAM CECI FOR ANALYSIS OF AN SCALAR FIELD ABOUT GRID
C PCINTS.PROVISION HAS BEEN MADE FOR MISSING DATA,VARIABLE
C GRID SIZE AN ROTATION OF GRID.XSC IS THE X-AXIS SCALE,
C YSC THE Y-AXIS SCALE,NR IS THE NUMBER OF STATIONS AVAILABL
C NMR IS THE NUMBER OF GRID LINES IN THE X-DIRECTION,MMR IS
C THE NUMBER OF GRID LINES IN THE Y-DIRECTION AND ANG IS THE
C RCTATION OF THE GRID.
      READ (5,898) (TITLE(I),I=1,12)
      READ (5,324) MESH,RMIN,RMAX,RICK
C RICK IS THE MEAN LATITUDE FOR THE GRID
      WRITE(6,325)
      WRITE(6,326) MESH,RMIN,RMAX,RICK
      READ(5,899) IS,JS,KS
      READ(5,401) ANG,IPAR,MI,INT,SINT,DELTA,EPSI
      WRITE(6,402)
      WRITE(6,430)ANG,IPAR,IM,INT,SINT,DELTA,EPSI
      READ(5,292) ILAT,RMINL,ILONG,RMING
      WRITE(6,290)
      WRITE(6,291)
      WRITE(6,293)ILAT,RMINL,ILONG,RMING
      READ(5,280)XSC,YSC,NMR,MMR,NR
      THET=0.01745*ANG
      RICK=0.01745*RICK
      JSC=1
      MJ1=4
      C=1.0
      READ(5,272)  (LAT(I),OMINL(I),LONG(I),OMING(I),DEPTH(I
     2,OB1(I),OB2(I),OB3(I),I=1,NR)
      WRITE(6,270)
      WRITE (6,271)
      WRITE(6,274) (LAT(I),OMINL(I),LONG(I),OMING(I),DEPTH(I
     2,OB1(I),OB2(I),OB3(I),I=1,NR)
C TO OBTAIN THE HCRIZONTAL GRID FROM A REFERENCE POINT WITH
C GEOGRAPHICAL POSITION ILAT,RMINL,ILCNG,RMING.THE GRID IS
C ROTATED,ANG,DEGREES AND TENTHS OF DEGRE.IPAR IS THE PARAME
C TER SELECTED FRCM THE  DATA CARD AND MI IS THE NUMBER OF
C OBSERVATIONS FOR EACH STATION ON THE VERTICAL GRID.FOR
C HCRIZONTAL GRID MI MUST BE ONE.
      WRITE (6,321)
      WRITE(6,322)
      DO 419 J=1,NR
  403 IF(ILAT-LAT(J))404,406,405
  404 LAT(J)=LAT(J)-1
      CMINL(J)=OMINL(J)+60.0
      GO TO 403
  405 LAT(J)=LAT(J)+1
      CMINL(J)=OMINL(J)-60.0
      GO TO 403
  406 IF(ILONG-LONG(J))407,409,408
  408 LCNG(J)=LONG(J)+1
      CMING(J)=OMING(J)-60.0
      GO TO 406
  407 LONG(J)=LCNG(J)-1
      CMING(J)=OMING(J)+60.C
      GO TO 406
```

```
409 XO(J)=(RMING-OMING(J))*COS(RICK)
    YO(J)=OMINL(J)-RMINL
    XOREL=XO(J)=COS(THET)-YO(J)*SIN(THET)
    YOREL=XO(J)*SIN(THET)+YO(J)*COS(THET)
    IF(MI.EQ.1) GO TO 411
C THE VERTICAL GRID IS OBTAINED
    XO(J)=((XOREL**2+YOREL**2)**0.5)*1852.4
    YO(J)=DEPTH(J)
    GO TO 410
411 XO(J)=XOREL
    YO(J)=YCREL
410 IF(IPAR-2)412,414,416
412 OBS1(J)=OB1(J)
    GO TO 418
414 OBS1(J)=OB2(J)
    GO TO 418
416 OBS1(J)=CB3(J)
418 WRITE(6,323)XO(J),YO(J),OBS1(J)
419 CONTINUE
  2 XC=XSC/2.0
    YC=YSC/2.0
    XR=(XC**2+YC**2)**0.5
    WRITE(6,349)
    WRITE(6,322)
    DO 15 L=1,MMR
    YG=YSC*L
  4 DO 15 K=1,NMR
    XG=XSC*K
    N=1
    DO 8 I=1,NR
    XOB=ABS(XO(I)-XG)
    IF(XOB.GT.XC) GO TO 8
    YOB=ABS(YO(I)-YG)
    IF(YOB.GT.YC) GO TO 8
    Z(N)=OBS1(I)
    X(N)=XO(I)-XG
    Y(N)=YO(I)-YG
  5 N=N+1
  8 CCNTINUE
    IF(N-2)10,12,14
 10 GVAL1(K,L)=0.0
    GO TO 15
 12 AP=(X(1)**2+Y(1)**2)**0.5
    IF(AP.GT.7.0) GO TO 10
    GVAL1(K,L)=Z(1)
    IF(GVAL1(K,L).LT.RMAX) GO TO 15
    GVAL1(K,L)=C.0
    GO TO 15
 14 N=N-1
    CALL INTERP(N,XR,POLY)
    GVAL1(K,L)=POLY
    IF(GVAL1(K,L).LT.RMAX) GO TO 15
    GVAL1(K,L)=0.0
 15 WRITE(6,350)XG,YG,GVAL1(K,L)
    N1=NMR-1
    N2=NMR-2
    M1=MMR-1
    M2=MMR-2
C INITIAL VALUE FOR U/K
C P IS THE RATIO OF THE TWO COMPONENTS OF THE VELOCITY VECTO
    RATIO=0.6
    WRITE (6,319)
    DO 150 M=1,MJ1
    DO 150 L=1,MMR
    P=0.27
    RAX=0.1
    RAY=C*(RATIO**2-RAX**2)**0.5
 41 DO 150 K=1,NMR
    IF(GVAL1(K,L).GT.0.1) GO TO 140
    IF(MI.EQ.1) GO TO 50
    IF(GVAL1(K,L+1).LT.0.01) GO TO 1104
    IF(GVAL1(K,L+2).LT.0.01) GO TO 1104
```

```
      MM=11
      GVAL1(K,L)=RAY*YSC*(GVAL1(K,L+1)-GVAL1(K,L+2))+2.0*
     2GVAL1(K,L+1)-GVAL1(K,L+2)
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1102
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1102
      GO TO 149
 1102 GVAL1(K,L)=0.0
 1104 IF(GVAL1(K,L-1).LT.0.01)GO TO 149
      IF(GVAL1(K,L-2).LT.0.01)GO TO 1106
      MM=12
      GVAL1(K,L)=RAY*YSC*(GVAL1(K,L-2)-GVAL1(K,L-1))+2.0*
     2GVAL1(K,L-1)-GVAL1(K,L-2)
      IF(ABS(GVAL1(K,L)).LT.RMIN)GO TO 1105
      IF(ABS(GVAL1(K,L)).GT.RMAX)GO TO 1105
      GO TO 149
 1105 GVAL1(K,L)=0.0
 1106 IF(GVAL1(K,L+1).LT.0.01) GO TO 149
      GVAL1(K,L)=(GVAL1(K,L-1)+GVAL1(K,L+1))/2.0-RAY*YSC*
     2(GVAL1(K,L-1)-GVAL1(K,L+1))/4.0
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1108
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1108
      GO TO 149
 1108 GVAL1(K,L)=0.0
      GO TO 149
   50 N=0
      IF(NMR-(K+1)) 51,54,42
   51 IF(L.EQ.MMR) GO TO 185
      GO TO 104
   54 IF(L.EQ.MMR) GO TO 81
      IF(L.EQ.1) GO TO 110
   42 IF(L.GT.M1) GO TO 75
      IF(L.EQ.1) GO TO 110
   80 IF(GVAL1(K+1,L+1).LT.0.1)GO TO 81
      IF(GVAL1(K+2,L).LT.0.1) GO TO 81
   83 IF(GVAL1(K+1,L-1).LT.0.1)GO TO 81
      N=7
   81 IF(GVAL1(K+1,L).LT.0.1)GO TO 103
      IF(N.LT.7) GO TO 100
      MM=8
      CALL MOLE(MM,K,L.XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RAX*DIV
      GVAL1(K,L)=GVAL1(K,L)-RAY*(GVAL1(K+1,L+1)-GVAL1(K+1,
     2L-1))/(2.0*YSC)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1008
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1008
      GO TO 149
 1008 GVAL1(K,L)=0.0
  100 IF(GVAL1(K,L-1).LT.0.1) GO TO  103
      IF(L.EQ.MMR) GO TO 104
      IF(GVAL1(K,L+1).LT.0.1) GO TO 103
      N=7
      GO TO 104
  103 N=0
  104 IF(K.LT.2) GO TO 132
      IF(GVAL1(K-1,L).LT.0.1) GO TO 110
      IF (N.LT.7) GO TO 108
      MM=9
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      DIV=(GVAL1(K+1,L)-GVAL1(K-1,L))*RAX/(2.0*XSC)+(GVAL1(
     2 K,L+1)-GVAL1(K,L-1))*RAY/(2.0*YSC)
      GVAL1(K,L)=GVAL1(K,L)-DIV
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1009
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1009
      GO TO 149
 1009 GVAL1(K,L)=0.0
  108 IF(L.LT.2) GO TO 110
      IF(GVAL1(K-1,L-1).LT.0.1) GO TO 110
      N=7
      GO TO 111
  110 N=0
      IF(K.LT.3) GO TO 132
  111 IF(GVAL1(K-2,L).LT.0.1) GO TO 114
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      IF(L.EQ.MMR) GO TO 114
  112 IF(GVAL1(K-1,L+1).LT.0.1) GO TO 114
      IF(N.LT.7) GO TO 113
      MM=4
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RAX*DIV
      GVAL1(K,L)=GVAL1(K,L)-RAY*(GVAL1(K-1,L+1)-GVAL1(K-1,
     2 L-1))/(2.0*YSC)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1004
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1004
      GO TO 149
 1004 GVAL1(K,L)=0.0
      GO TO  113
  114 N=0
      GO TO 115
  113 N=7
  115 IF(L.EQ.M1) GO TO 75
      IF(N.LT.7) GO TO 132
      IF(GVAL1(K-2,L+2).LT.0.1) GO TO 132
      N=N+8
  132 IF(L.GT.M2) GO TO 136
      IF(GVAL1(K,L+2).LT.0.1) GO TO 134
      IF(N.LT.15) GO TO 136
      MM=3
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RATIO*DIV
      GVAL1(K,L)=GVAL1(K,L) -RATIO*(GVAL1(K,L+2)-GVAL1(K-2,
     2 L))/(2.0*XR)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1003
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1003
      GO TO 149
 1003 GVAL1(K,L)=0.0
  134 IF(K.EQ.NMR) GO TO 75
      GO TO 149
  136 N=0
      IF(L.GT.M1) GO TO 75
      IF(K.GT.N1) GO TO 75
      IF(GVAL1(K+1,L+1).LT.0.1)GO TO 75
      IF(L.GT.M2) GO TO 148
      IF(K.GT.N2) GO TO 148
      IF(GVAL1(K+2,L).LT.0.1)GO TO 148
      IF(GVAL1(K+2,L+2).LT.0.1) GO TO 148
      MM=1
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RATIO*DIV
      GVAL1(K,L)=GVAL1(K,L) -RATIO*(GVAL1(K,L+2)-GVAL1(K+2,
     2 L))/(2.0*XR)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1001
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1001
      GO TO 149
 1001 GVAL1(K,L)=0.0
  148 IF(K.GT.N1) GO TO 75
      IF(L.GT.M1) GO TO 75
      IF(K.LT.2) GO TO 75
      IF(GVAL1(K,L+1).LT.0.1) GO TO 75
      IF(GVAL1(K-1,L+1).LT.0.1) GO TO 75
      MM=2
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RAY*DIV
      GVAL1(K,L)=GVAL1(K,L) -RAX*(GVAL1(K-1,L+1)-GVAL1(K+1,
     2 L+1))/(2.0*XSC)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1002
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1002
      GO TO 149
 1002 GVAL1(K,L)=0.0
   75 IF(L.LT.3) GO TO 149
   82 IF(K.GT.N2) GO TO 185
      IF(GVAL1(K+2,L).LT.0.1) GO TO 185
      N=1
  185 IF(K.EQ.NMR) GO TO 85
      IF(GVAL1(K+1,L-1).LT.0.1)GO TO 85
      N=N+2
```

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   85 IF(GVAL1(K,L-2).LT.0.1) GO TO 149
      N=N+4
      IF(K.GE.N2) GO TO 91
      IF(GVAL1(K+2,L-2).LT.0.1) GO TO 91
      IF(N.LT.7) GO TO 91
      MM=7
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RATIO*DIV
      GVAL1(K,L)=GVAL1(K,L) -RATIO*(GVAL1(K+1,L )-GVAL1(K,L-1
     2 ))/(2.0*XR)
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1007
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1007
      GO TO 149
 1007 GVAL1(K,L)=0.0
   91 IF(K.LT.2) GO TO 149
      IF(GVAL1(K-1,L-1).LT.0.1) GO TO 149
      N=N+8
      IF(GVAL1(K,L-1).LT.0.1) GO TO 96
   94 IF(N.LT.14) GO TO 96
      MM=6
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RAY*DIV
      GVAL1(K,L)=GVAL1(K,L) -RAX*(GVAL1(K+1,L-1)-GVAL1(K-1,
     2 L-1))/(2.0*XSC)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1006
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1006
      GO TO 149
 1006 GVAL1(K,L)=0.0
   96 IF(GVAL1(K-2,L-2).LT.0.1) GO TO 149
      IF(GVAL1(K-2,L).LT.0.1)GO TO 149
      IF(N.LT.12) GO TO 149
      MM=5
      CALL MOLE(MM,K,L,XSC,YSC,DIV)
      GVAL1(K,L)=GVAL1(K,L)-RATIO*DIV
      GVAL1(K,L)=GVAL1(K,L) -RATIO*(GVAL1(K,L-2)-GVAL1(K-2,L
     2 ))/(2.0*XR)
      IF(ABS(GVAL1(K,L)).GT.RMAX) GO TO 1005
      IF(ABS(GVAL1(K,L)).LT.RMIN) GO TO 1005
      GO TO 149
 1005 GVAL1(K,L)=0.0
      GO TO 149
  140 IF(MI.EQ.1)GO TO 142
      IF(GVAL1(K,L+1).LT.0.01) GO TO 149
      IF(GVAL1(K,L-1).LT.0.01) GO TO 149
      RAY=2.0*(GVAL1(K,L-1)-2.0*GVAL1(K,L)+GVAL1(K,L+1))/
     2(YSC*(GVAL1(K,L-1)-GVAL1(K,L+1)))
      GO TO 154
  142 IF(GVAL1(K,L-2).LT.0.1) GO TO 149
      IF(GVAL1(K-2,L).LT.0.1)GO TO 149
      IF(GVAL1(K-1,L).LT.0.1) GO TO 149
      IF(GVAL1(K,L-1).LT.0.1) GO TO 149
      PRS=XSC*(GVAL1(K,L)-GVAL1(K-1,L))+P*YSC*(GVAL1(K,L)-
     2 GVAL1(K,L-1))
      IF(ABS(PRS).LT.EPSI) GO TO 149
      ROX=(GVAL1(K,L)-2.0*GVAL1(K-1,L)+GVAL1(K-2,L)+GVAL1(K,
     2GVAL1(K,L-1)+GVAL1(K,L-2))/PRS
      IF(ABS(ROX).GT.30.0) GO TO 149
      IF(ABS(ROX).GE.RATIO)GO TO 1021
      RAX=ROX
      GO TO 1022
 1021 RAX=RATIO
      RAY=0.0
      GO TO 1024
 1022 B=(RATIO**2-RAX**2)**0.5
      IF(RAX.GT.0.0)GO TO 1023
      RAY=-C*B
      GO TO 1024
 1023 RAY=C*B
 1024 IF(M.LT.MJ1) GO TO 157
  153 IF(ABS(RAY).LT.EPSI) GO TO 1053
      IF(ABS(RAX).LT.EPSI) GO TO 1054
      P=RAY/RAX
```

```
      GO TO 154
 1053 IF(ABS(RAX).LT.EPSI) GO TO 1055
      P=EPSI/RAX
      GO TO 154
 1054 P=RAY/EPSI
      GO TO 154
 1055 P=1.0
  154 WRITE(6,323) RAX,RAY,RATIO,K,L
  149 IF(M.LT.MJ1) GO TO 157
  157 IF(GVAL1(K,L).GT.RMIN) GO TO 150
      GVAL1(K,L)=0.0
  150 CONTINUE
      IF( JSC.EQ.MESH) GO TO 170
      N=1
      SUM=0.0
      DO 162 L=1,MMR
      YG=YSC*L
      DO 162 K=1,NMR
      XG=XSC*K
      IF(GVAL1(K,L).LT.0.1) GO TO 162
      OBS1(NR+N)=GVAL1(K,L)
      YO(NR+N)=YG
      XC(NR+N)=XG
      N=N+1
      SUM=SUM+GVAL1(K,L)
  162 CONTINUE
      AVER=SUM/(FLOAT(N-1))
      NR=NR+N
      JSC=JSC+1
      NMR=2*NMR
      MMR=2*MMR
      XSC=XSC/2.0
      YSC=YSC/2.0
      MJ1=3*MJ1
      WRITE(6,280) XSC,YSC,NMR,MMR,NR
      GO TO 2
  170 DO 173 L=1,MMR
      I3=MMR+1
      I=I3-L
      YG=YSC*L
      DO 173 K=1,NMR
      XG=XSC*K
      IF(GVAL1(K,L).GT.0.1) GO TO 172
      GVAL1(K,L)=AVER
  172 XGA=XG*COS(THET)+YG*SIN(THET)
      YGA=-XG*SIN(THET)+YG*COS(THET)
      XGA=RMING-XGA
      YGA=RMINL+YGA
      G(K,I)=GVAL1(K,L)
  173 CONTINUE
      WRITE(6,255)
      WRITE(6,256)
      WRITE(6,259) ((GVAL1(K,L),K,L,K=1,NMR),L=1,MMR)
      IDR=INT-1
      DO 171 I=1,IDR
      CL(1)=SINT
  171 CL(I+1)=CL(I)+DELTA
      LTG(1)=IS.EQ.2
      LTG(2)=JS.EQ.2
      LTG(3)=KS.EQ.2
      CALL CONTUR (GVAL1,NMR,MMR,50,CL,INT,TITLE,9,21,LTG)
  204 FORMAT(F10.4,F15.4,F10.2)
  255 FORMAT ('0',24X,28HFINAL VALUES FOR GRID POINTS,/)
  256 FORMAT('0',30X,4HTEMP,5X,1HK,5X,1HL)
  258 FORMAT(2X,  F15.2,3I5 )
  259 FORMAT(21X, F15.2,2I5 )
  270 FORMAT('0',40X,22HOCEANOGRAPHIC STATIONS,/)
  271 FORMAT('0',20X,8HLATITUDE,7X,9HLONGITUDE,8X,5HDEPTH,5X
     2 4HTEMP,2X,11HSOUND VELOC,/)
  272 FORMAT(I5,F10.2,I5,5F10.2)
  273 FORMAT(12X,3F15.4)
  274 FORMAT(20X,I5,F10.2,I5,5F10.2)
```

```
280 FORMAT(2F10.0,3I5)
284 FORMAT(5X,2F10.4,3I5)
290 FORMAT('0',20X,36HPOSITION OF THE GRID REFERENCE POINT
291 FORMAT(26X,8HLATITUDE,6X,9HLONGITUDE,/)
292 FORMAT(I5,F10.0,I5,F10.0)
293 FORMAT(22X,2(I5,F10.3))
319 FORMAT('0',20X,3HU/K,12X,3HV/K,12X,5HRATIO,2X,1HK,4X,1
321 FORMAT('1',30X,29HRELATIVE POSITION IN THE GRID,/)
322 FORMAT(20X,1HX,15X,1HY,10X,9HPARAMETER,/)
323 FORMAT(10X,3F15.3,2I5)
324 FORMAT(I5,3F10.3)
325 FORMAT('1',20X,4HMESH,2X,7HMINIMUM,3X,7HMAXIMUM,2X,8HM
326 FORMAT(18X,I5,3F10.3)
349 FORMAT('1',40X,32HINTERPOLATED VALUES FOR THE GRID,/)
350 FORMAT(12X,3F15.5)
401 FORMAT(F10.2,3I5,3F10.3)
402 FORMAT('0',23X,8HROTATION,1X,5HPARAM,1X,4HGRID,2X,3HIN
   22X,7HINITIAL,2X,9HINCREMENT,2X,7HEPSILON)
430 FORMAT(22X,F10.2,3I5,3F10.3)
888 FORMAT(2X,3I5,F15.2,5X,I5,F15.2)
890 FORMAT(2X,49HTHE FOLLOWING POINT HAVE RECIVED AN AVERA
898 FORMAT(6A8)
899 FORMAT(3I5)
    STOP
    END

    SUBROUTINE INTERP(N,XR,POLY)
C PROGRAM FOR LEAST SQUARE SURFACE INTERPOLATION UP TO SECON
    COMMON/PARAM/X(20),Y(20),Z(20)
    DIMENSION C(6,6),B(6)
    IF(N.LT.3) GO TO 20
    M=6
    DO 2 I=1,6
    B(I)=0.0
    DO 2 K=1,6
  2 C(K,I)=0.0
    C(1,1)=N
    DO 5 J=1,N
    C(1,2)=C(1,2)+X(J)
    C(1,3)=C(1,3)+Y(J)
    C(1,4)=C(1,4)+X(J)**2
    C(1,5)=C(1,5)+X(J)*Y(J)
    C(1,6)=C(1,6)+Y(J)**2
    C(2,4)=C(2,4)+X(J)**3
    C(2,5)=C(2,5)+Y(J)*X(J)**2
    C(2,6)=C(2,6)+X(J)*Y(J)**2
    C(3,6)=C(3,6)+Y(J)**3
    C(4,4)=C(4,4)+X(J)**4
    C(4,5)=C(4,5)+Y(J)*X(J)**3
    C(4,6)=C(J,6)+(X(J)**2)*(Y(J)**2)
    C(5,6)=C(5,6)+X(J)*Y(J)**3
    C(6,6)=C(6,6)+Y(J)**4
    B(1)=B(1)+Z(J)
    B(2)=B(2)+Z(J)*X(J)
    B(3)=B(3)+Z(J)*Y(J)
    B(4)=B(4)+Z(J)*X(J)**2
    B(5)=B(5)+Z(J)*X(J)*Y(J)
  5 B(6)=B(6)+Z(J)*Y(J)**2
    C(5,5)=C(4,6)
    C(3,5)=C(2,6)
    C(3,4)=C(2,5)
    C(3,3)=C(1,6)
    C(2,2)=C(1,4)
    C(2,3)=C(1,5)
    DO 7 I=1,6
    DO 7 K=1,6
  7 C(K,I)=C(I,K)
    IF(N.GT.5) GO TO 10
    M=4
    DO 9 I=1,6
    C(4,I)=C(5,I)
```

```
    9 C(I,4)=C(I,5)
      B(4)=B(5)
   10 CALL SIMQ (C,B,M,KS)
      POLY=B(1)
      GO TO 42
   20 IF(( X(1)- X(2)).LT.EPSI) GO TO 22
      IF(( Y(1)- Y(2)).LT.EPSI) GO TO 26
      CM=(Z(1)-Z(2))*(X(1)*(Y(1)-Y(2))+Y(1)*(X(1)-X(2)))/
     2((X(1)-X(2))*(Y(1)-Y(2)))
      GO TO 28
   22 IF(( Y(1)- Y(2)).LT.EPSI) GO TO 24
      CM=(Z(1)-Z(2))*Y(1)/(Y(1)-Y(2))
      GO TO 28
   24 POLY=( Z(1)+ Z(2))/2.0
      GO TO 42
   26 CM=(Z(1)-Z(2))*X(1)/(X(1)-X(2))
   28 XY=(X(1)**2+Y(1)**2)**0.5
      CS=1.5703*XY/XR
      POLY=Z(1)-CM
   42 RETURN
      END


      SUBROUTINE MOLE (MM,K,L,XSC,YSC,DIV)
      COMMON/GRID/U(50,50)
      FAC1=(XSC/YSC)**2
      FAC2=(YSC/XSC)**2
      XR=(XSC**2+YSC**2)**0.5
      GO TO (1,2,3,4,5,6,7,8,9),MM
    1 U(K,L)=4.0*U(K+1,L+1)-U(K,L+2)-U(K+2,L) -U(K+2,L+2)
      DIV=(U(K+1,L+1)-U(K+2,L+2))/XR
      GO TO 10
    2 U(K,L)=-FAC2*(U(K+1,L+1)-2.0*U(K,L+1)+U(K-1,L+1))+2.0*
     2 U(K,L+1)-U(K,L+2)
      DIV=(U(K,L+1)-U(K,L+2))/YSC
      GO TO 10
    3 U(K,L)=4.0*U(K-1,L+1)-U(K,L+2)-U(K-2,L)-U(K-2,L+2)
      DIV=(U(K-1,L+1)-U(K-2,L+2))/XR
      GO TO 10
    4 U(K,L)=-FAC1*(U(K-1,L+1)-2.0*U(K-1,L)+U(K-1,L-1))+2.0*
     2 U(K-1,L)-U(K-2,L)
      DIV=(U(K-1,L)-U(K-2,L))/XSC
      GO TO 10
    5 U(K,L)=4.0*U(K-1,L-1)-U(K-2,L)-U(K,L-2)-U(K-2,L-2)
      DIV=(U(K-1,L-1)-U(K-2,L-2))/XR
      GO TO 10
    6 U(K,L)=-FAC2*(U(K+1,L-1)-2.0*U(K,L-1)+U(K-1,L-1))+2.0*
     2 U(K,L-1)-U(K,L-2)
      DIV=(U(K,L-1)-U(K,L-2))/YSC
      GO TO 10
    7 U(K,L)=4.0*U(K+1,L-1)-U(K+2,L)-U(K,L-2)-U(K+2,L-2)
      DIV=(U(K+1,L-1)-U(K+2,L-2))/XR
      GO TO 10
    8 U(K,L)=-FAC1*(U(K+1,L+1)-2.0*U(K+1,L)+U(K+1,L-1))+2.0*
     2 U(K+1,L)-U(K+2,L)
      DIV=(U(K+1,L)-U(K+2,L))/XSC
      GO TO 10
    9 U(K,L)=(U(K+1,L)+FAC1*(U(K,L+1)+U(K,L-1))+U(K-1,L))/(
     2 2.0*FAC1+2.0)
   10 RETURN
      END
```

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1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Small Computer Analysis of Regional Ocean Data

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)
Master's Thesis; September 1971

5. AUTHOR(S) (First name, middle initial, last name)
Jaime C. Sanchez

6. REPORT DATE September 1971	7a. TOTAL NO. OF PAGES 86	7b. NO. OF REFS 18
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

This study presents the results of an experiment in objective analysis of oceanographic data for a limited area. The objective analysis is designed to provide a reliable operational system for tactical use in coastal waters. It is shown that this approach makes it possible to obtain a very detailed analysis with good vertical consistency and that only a relatively small amount of highly accurate data is required. The procedure includes a polynomial interpolation and a dynamical interpolation. The dynamical interpolation which is introduced involves the analytical solution of a finite differential equation by means of a rotational computing molecule. The procedure requires only a small computer and little computer time. This method will provide a basis for short-time forecasts of oceanographic parameters using only small computer centers or even time sharing systems.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

Unclassified
Security Classification

A-31408

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Small Computer Analysis						
Regional Ocean Data						

130718
Thesis
S1579 Sanchez
c.1 Small computer analysis of regional ocean data.